2003-09

An estimation of the ability to forecast boundary layer mixing height and wind parameters through forecast verification over Fort Ord

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http://hdl.handle.net/10945/6316

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THESIS

AN ESTIMATION OF THE ABILITY TO FORECAST BOUNDARY LAYER MIXING HEIGHT AND WIND PARAMETERS THROUGH FORECAST VERIFICATION OVER FORT ORD

by

Claude F. Gahard

September 2003

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REPORT DOCUMENTATION PAGE	*Form Approved OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	**2. REPORT DATE** September 2003	**3. REPORT TYPE AND DATES COVERED** Master's Thesis

4. TITLE AND SUBTITLE: An Estimation of the Ability to Forecast Boundary Layer Mixing Height And Wind Parameters through forecast verification over Fort Ord

5. FUNDING NUMBERS

6. AUTHOR(S) Gahard, Claude F.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey, CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES)
N/A

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(maximum 200 words)*

Conducting controlled burns at Fort Ord requires specific meteorological and operational criteria. A minimum five-mile per hour offshore wind flow in conjunction with a minimum lower vertical mixing height of 1500 ft is meteorologically required. Burn contractor operational constraints require these meteorological parameters to be forecast 72 hours prior to burn.

This study establishes forecast verification percentage baselines for offshore and onshore winds. These forecasts are verified by analyses at 850 mb and profiler observations, from the surface to 1500 ft, at 24, 48, and 72 hr forecast durations. From these baselines the forecast skill when including a second burn prescription parameter, lower vertical mixing height, is inferred.

Resulting forecast verification percentages using profiler observations of offshore wind flow were less than 40% at all forecast durations. Results indicate that during the burn season (July through December) the synoptic scale forecasts do not adequately represent the local wind field over Fort Ord. As the burn season progresses synoptic scale forcing becomes stronger and mesoscale forcing weakens over Fort Ord, favoring forecast verification with profiler observations. Lastly, the inferred forecast skill of both offshore wind flow from the surface to 1500 ft and the minimum vertical lower mixing height simultaneously at all durations is 10%.

14. SUBJECT TERMS
Forecast Verification, Doppler Radar Wind Profiler Observations, AVN Simulations, Fort Ord, Chemical/Biological Defense

15. NUMBER OF PAGES
85

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	**18. SECURITY CLASSIFICATION OF THIS PAGE**	**19. SECURITY CLASSIFICATION OF ABSTRACT**	**20. LIMITATION OF ABSTRACT**
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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AN ESTIMATION OF THE ABILITY TO FORECAST BURN PRESCRIPTION PARAMETERS THROUGH FORECAST VERIFICATION OVER FORT ORD

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN METEOROLOGY AND PHYSICAL OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL
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ACKNOWLEDGMENTS

I would like to sincerely thank everyone who assisted in the completion of this study and my degree. Dr Wendell Nuss for his patience, extensive meteorological knowledge, and oversight over the entire thesis process. I was blessed with an opportunity for which I am truly grateful. LCDR Dave Brown for informing me that Dr Nuss was looking for someone to "work some data", being my second reader, and a great lab instructor. Dick Lind for his lack of complaint, in depth profiler knowledge, and for teaching me the finer points of cribbage. Bob Creasy, for providing me with archived AVN model data, UNIX support, and a mutual appreciation of AC/DC in the IDEA lab.

Additionally, I would like to extend a special thanks to my classmates CDR MEX Juan Aguilar (a.k.a. Commander), LCDR Victor Ross (a.k.a. $(Vr)^2$), LCDR Dominick Vincent (a.k.a. Nicky), and LT Jeffery Dixon (a.k.a. Hef-ee). Without their support I never would have made it through the classes at NPS. Lastly, I would like to thank LCDR Jon Dumas, LCDR Ash Evans, and LT Wendy Towle for their priceless academic contributions.

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I. INTRODUCTION

A. MOTIVATION

The former Fort Ord Army base covers approximately 28,000 acres in Monterey County, CA. A large portion of the base is populated with unexploded ordinance (UXO) from years of accumulation. Much of the UXO is located among thick vegetation and undergrowth. A controlled burn at the former Fort Ord was ignited on August 25, 1997. The purpose of the burn was to clear 400 acres of land to enable the removal of the UXO so that the area could be remediated for future development. When the fire was extinguished it had accidently incinerated 700 acres and inundated the Salinas Valley with noxious smoke (Fig. 1). Because of this the Monterey Bay Air Pollution Control district (MBAPCD) filed a lawsuit against the United States Army.

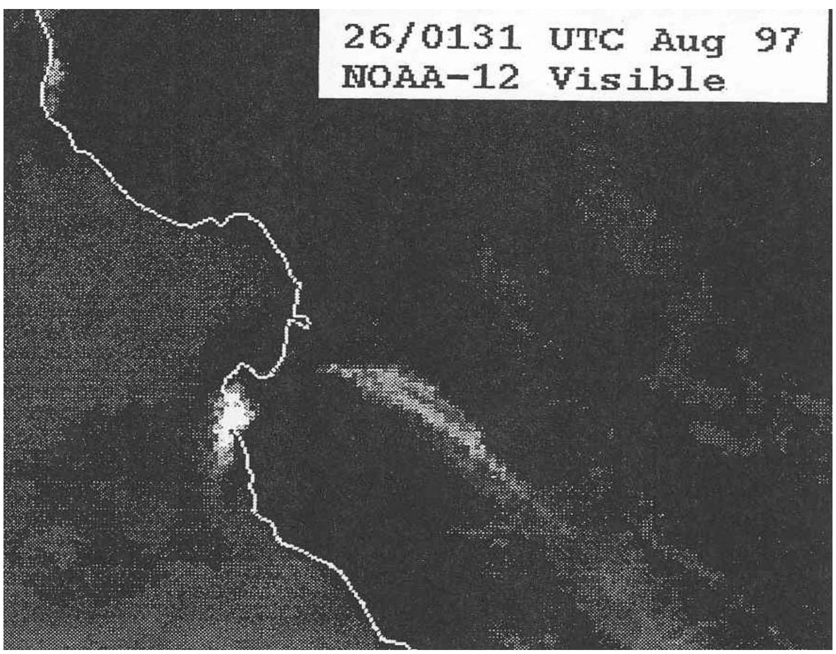

FIGURE 1. A NOAA-12 visible satellite image of the smoke plume from the Fort Ord fire advected into the Salinas Valley at 01:31 UTC 26 August 1997.

A settlement was reached in April of 2002 between the Army and the MBAPCD. It was established that controlled burns were essential to clear areas of UXO and for habitat management at Fort Ord. It also mandated smoke dispersion studies at the former Army base were needed in order to gain a better understanding of how the complex coastal meteorology influenced the selection of burn days.

Three criteria were required for the burn day on 25 August 1997 as dictated the by the California Air Resources Board (CARB), the supervisory organization to MBAPCD. The first was an averaged minimum wind speed of five mph within a layer from the surface to 1500 ft. The second being a minimum lower mixing height, represented as a function of virtual temperature, of at least 1500 ft. Lastly, a minimum day time temperature of $55^{o}F$ must occur. Even with these three requirements, the city of Salinas and the surrounding areas were still inundated by acrid smoke due to an unanticipated sea breeze (Taylor 1998).

This event motivated the Army to incorporate meteorologist input and a fourth meteorological prerequisite added to the CARB parameters for conducting a controlled burn at Fort Ord. This was the prerequisite of offshore flow at the surface to counteract the effects of onshore flow, a sea breeze for example (Nuss 2003). In addition to the meteorological requirements, there are operational requirements that need to be addressed.

Operational motivation for this study results from two constraints required by the burn contractor. The first criteria is the requirement for a 72 hr forecast of offshore flow. The 72 hr lead time is necessary to stage equipment and notify the surrounding community of the proposed controlled burn. Second, knowing the percentage

of time that false forecasts occur at 24, 48, and 72 hrs is critical to allow the contractor to establish a cost to performance metric of the forecast being utilized. The combination of the meteorological and operational constraints creates a unique situation that the objectives of this study attempt to address.

B. OBJECTIVES

The operational constraints in conjunction with a need to establish a quantitative baseline, relative to at least one of three major meteorological criteria previously mentioned, dictated the two main objectives of this study, which are:

1. To establish how often 24, 48, and 72 hr synoptic model forecasts of 850 mb wind direction over Fort Ord verified within 45 degrees of corresponding analyses through verification percentages.

2. To determine how often, and attempt to explain why, these forecasts verified or did not verify with profiler observations of average wind direction in the layer from the surface to 1500 ft above Fort Ord.

The verification percentages can be used to assess false alarm rates through the following equation: verification percentage – 100 = false alarm percentage. The verification percentage is the number of forecasts that verified divided by the total number of forecasts. Data collected to address both objectives occurred during the burn season, which extends from July through December, for the years 2000 through 2002. Note, there are other

criteria required to complete a controlled burn in addition to wind direction, speed and mixing height, which were not examined but will be addressed during the discussion and conclusions chapter

This research has implications for the use of synoptic scale models in areas of forecasting conditions for controlled burns, dispersion air pollution, and air quality control in a coastal environment, especially for forecast durations of 72 hours. If the AVN demonstrates substantial accuracy in forecasting wind direction over Fort Ord it could be a candidate to reliably initialize higher resolution mesoscale models such as the Coupled Ocean/Atmospheric Mesoscale Predition System (COAMPS) or the PSU/NCAR mesoscale model (MM5).

II. BACKGROUND

Forecasting burn prescription parameters, specifically wind direction, requires an understanding of the synoptic and mesoscale meteorology over the Fort Ord area. The following is an overview and description of general traits of these two different scales of weather and possible interactions between them. Additionally, archived wind profiler observations since 1995 are used to provide a historical perspective on how infrequently all three-burn prescription parameters combine to create burn days.

A. SYNOPTIC METEOROLOGY

During the first three months of the burn season (July through September) the sun exposes the northern hemisphere to maximum direct short wave solar radiation and heating. This is a result of the relative position between the earth and sun and occurs between the summer solstice (June 22nd) and the autumnal equinox (September 23rd). During this time the sun's zone of maximum heating moves southward from the northern hemisphere's Tropic of Cancer towards the equator.

This process causes the polar vortex in the northern hemisphere to expand and strengthen from its minimum state during the summer months creating changes in the synoptic weather patterns. An increasing thermal gradient in the northern hemisphere causes the Polar Front Jet to increase in strength and its mean position begins to move southward from Canada towards the United States. Additionally, the Aleutian low located in the upper latitudes of the Gulf of Alaska, tends to deepen and move southward, while the semi

permanent high off the coast of California begins to weaken. Thermal lows usually develop over the southwestern United States during the summer as well. During this time period, vertical thermal stratification is quite prevalent over the California coastline. An examination of vertical soundings of the atmosphere at Oakland, Vandenberg Air Force Base and San Diego during the summer months reveals a well defined temperature inversion that separates the marine boundary layer (MBL) from the free atmosphere above nearly 90% of the time and half the time during the winter (Dorman et al 1995).

The last three months of the burn season (October through December) begins after the autumnal equinox (September 23rd) and ends after the winter solstice (December 22nd). During this time the sun's mean position is continuing southward over the equatorial regions towards the southern hemisphere's Tropic of Capricorn. The sun's zone of maximum heating is entirely in the southern hemisphere promoting the Polar Front Jet's mean position to move further southward over the U.S., as its thermal gradient continues to strengthen. The Aleutian low continues to deepen and moves southward in the Gulf of Alaska. The semi permanent high off the coast of California continues to weaken and there is an increase in the frequency of extratropical storm tracks that transit over the west coast of the U.S. During the last three months of the burn season vertical thermal stratification off the California coast reduces (Dorman et al 1995). This stratification is occasionally eliminated during the passages of extratropical cyclones.

B. MESOSCALE METEOROLOGY

Sea and land breezes are thermally induced circulations that develop at the coastal boundary. They occur due to differences in the radiative properties between the ocean and the land surfaces and the resulting induced thermal gradient. Land absorbs the short wave solar radiation much more effectively than the ocean resulting in different heat fluxes into the boundary layer above. During the daytime, the land surface heat flux is transferred into the boundary layer while the marine boundary layer remains cool, creating onshore flow due to a resultant cross-shore pressure gradient. At night, the thermal gradient reverses due to radiational cooling, creating a cooler land surface as compared to that over the ocean. This promotes a nocturnal offshore flow or a land breeze. It should be noted that the offshore flowing land breeze is not as intense as a sea breeze either in velocity or depth. This is due to a weaker heat source shallower structure compared to the sea breeze (Atkinson 1981). These thermally induced circulations are functions of the reflection and absorption of incoming solar radiation, and are therefore effected by the time of year. Additionally, factors such as latitude, type of land surfaces, and synoptic scale background also affect the diurnally induced thermal gradient.

In the northern hemisphere during the late summer, the first three months of the burn season, days tend to be longer with the sun being more directly over head than the last three months of the burn season. This provides greater heating of the land surfaces, resulting in a more concentrated alongshore thermal gradient, pressure

gradient, and stronger sea breezes. The latter three months of the burn season, October, November, and December experience relatively less solar short wave radiation over the Fort Ord area resulting in diminished thermal gradients and weaker sea and land breezes. More specific studies of the sea breeze reveal unique climatological trends.

The time of maximum wind occurrence and average speed of sea breezes over Monterey Bay have been investigated (Round 1993). The study determined that the average time of maximum wind occurrence was at 1400 PST. The most prevalent average maximum wind speed during these events was determined to be 8 m/s.

C. INTERACTIONS

Interactions between the synoptic scale and mesoscale and their effect on onshore and offshore flows can be addressed by examining two local effects. Examining the influence of the synoptic scale on the mesoscale thermal gradient through the use of numerical studies is one example. A second is illustrated through the interaction between synoptic surface pressure gradients combined with flow blocking by local topography to illustrate gap flow.

1. Synoptic Scale Flow Influences

Synoptic scale flow has important influence on local sea/land breeze circulations. When synoptic flow is in the same direction as the mesoscale flow, the temperature and pressure gradients are weakened. If the gradient flow is in the opposite direction, the opposing flow aids in the concentration of the temperature and pressure gradients, which enhances the thermally induced flow.

Relationships between large-scale flow and sea breezes have been examined and reproduced in numerical model studies (Aritt 1993). From a database of 31 sea breeze simulations investigating the effects of ambient winds ranging from 15 m/s onshore to 15 m/s offshore. Aritt classified sea breeze dependence on synoptic flow into four categories.

1. Moderate onshore synoptic flow: The large-scale flow is in the same direction as the sea breeze and results in a weak thermal perturbation of the large-scale flow.

2. Calm to moderate offshore synoptic flow: This is associated with the most intense sea breezes. The intensity of the thermally induced perturbations increases for stronger opposing flow.

3. Strong offshore synoptic flow: Vertical motions are suppressed. The horizontal velocities are weakened.

4. Very strong offshore synoptic flow: Vertical velocities and horizontal temperature gradients are weak.

It was concluded that slight onshore synoptic flow is sufficient to suppress a thermally induced sea breeze. In contrast, offshore synoptic flow up to 11 m/s permits sea breeze formation, with the strongest sea breeze circulations occurring during light offshore winds. This is important when considering the offshore flow burn prescription parameter. In addition to understanding how synoptic wind flows can cause different thermally induced circulations, ageostrophic flows induced by topography and synoptic surface pressure gradients can also be relevant over the Fort Ord area.

2. Gap Winds

Gap winds are ageostrophic flows that can occur when two specific conditions are met simultaneously (Nuss 2002). The first is when the Rossby radius of deformation (Rd) is greater than the width of the channel (W) in which the flow is occurring. The second condition requires an along channel mesoscale pressure gradient. The Rossby radius of deformation can be represented by the following equations:

$$Rd = V/f \quad (1)$$

$$Rd > W \quad (2)$$

The velocity at the mouth of the channel divided by the average value of Coriolis at 45^{o} north latitude equals the Rossby radius of deformation (1). When Rd is greater than the width of the channel (2) through which flow is occurring (W), the first requirement of ageostrophic flow is met. Substituting (1) into (2) and solving for V, then setting the two sides equal, allows for the determination of the minimum wind speed the along channel mesoscale pressure gradient needs to support ageostrophic flow. Using values of W and f representative of the Salinas valley, 10,000 m and 10^{-4} s^{-1}, respectively, one can establish a minimum V of 1.0 m/s or 2.0 kts that is required at the mouth of the Salinas valley to satisfy the first gap wind condition.

The second condition required is the along channel mesoscale pressure gradient. Both conditions must be met simultaneously to observe gap flow and are represented by (3).

$$V = (v^2(0) - (2(\Delta P)/\rho))^{1/2} \quad (3)$$

V is the maximum along channel velocity at the mouth of the channel. The second term $v^2(0)$ is the initial velocity of

the along channel flow prior to the mesoscale pressure gradient. The third term $2(\Delta P)/\rho$, is the pressure gradient in pascals divided by the approximate density of the flow. Assuming there the initial along channel flow is zero, $v^2(0)=0$, (3) simplifies to the maximum velocity at the mouth of the channel and is directly proportional to the mesoscale along channel pressure gradient. Values observed in the Salinas valley of -2.5 mb or -250 pa along channel pressure gradient, with a $\rho \sim 1.0$ kg/m^3, produce a $V \sim 22$ m/s or 44 kts. This speed and the previous conditions were observed during the 2000-2003 burn seasons, and will be illustrated in the last example of chapter V.

D. HISTORICAL PERSPECTIVE OF ACCEPTABLE BURN DAYS

A review of the historical trends of when all three burn conditions have been met simultaneously, meeting the prerequisites of a burn day, was conducted to put the forecast problem into perspective. The results listed in Table 1, obtained from wind profiler observations over Fort Ord demonstrates a limited number of acceptable burn days from 1995 to 2002, during the July-December burn season. The eight-year dataset produced an average 6.5 burn days per burn season (Nuss 2003). The extent to which multiple day episodes occurred during the burn season can be gauged by comparing the event frequency to the total number of days. An event is defined as any acceptable day or consecutive days. Table 1 shows the event frequency. The number in parenthesis is almost the same as the acceptable day frequency, indicating very few multiple day episodes.

Year	Number of days that met burn prescription criteria (events)	Number additional days if light onshore flow is considered as acceptable
2002	4 (4)	4
2001	3 (3)	3
2000	6 (5)	6
1999	5 (5)	7
1998	5 (5)	9
1997	12 (8)	3
1996	9 (8)	5
1995	8 (7)	3
Average	6.5 (5.6)	5

TABLE 1. Number of burn days and additional burn days by year if onshore flow allowed as burn prescription parameter.

Table 1 also contains the number of additional burn days that occur if light to nonexistent onshore flow is accepted as a burn prescription parameter.

The frequency of acceptable burn days by week, from September through December from 1995 to 2002, is also informative. The histogram shown in Fig. 2 indicates that most of the days that met all three burn prescription parameters occur between October 15 and November 15 (Nuss 2003). The reduction in frequency prior to October 15 is due to offshore flow events that occur which do not promote adequate lower vertical mixing heights. The reduction after November 15 is a direct result of not including events due to excessive cold temperatures. During this time, cold events occur in the area where temperatures are less than 55 degrees Fahrenheit. These cold event days

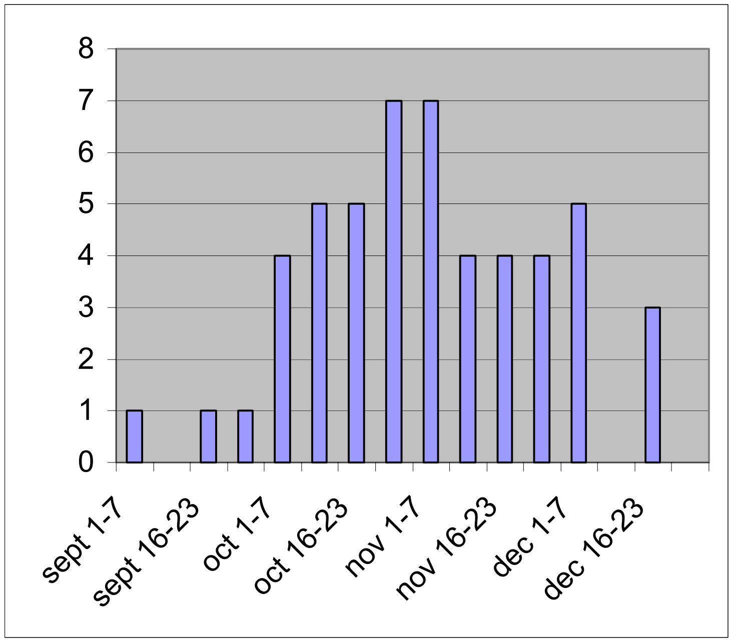

FIGURE 2. Histogram of the number of acceptable burn days by week, based on wind profiler observations.

tend to follow precipitation events, although no attempt was made to account for actual amounts of accumulated rainfall and increasing fuel moisture beyond acceptable maximums to conduct a controlled burn. This historical examination of actual acceptable burn days indicates their relative infrequency, which poses a significant forecast challenge.

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III. REMOTE SENSING EQUIPMENT AND THE MODEL

The Naval Postgraduate School (NPS) 915 MHz Doppler Radar Wind Profiler (RWP) with Radio Acoustics Sounding System (RASS), located at 36.69^o N latitude and 121.76^o W longitude, north of Marina's municipal airport, formerly Frizche Army airfield, is the primary source of local observational data for this study. The RWP was configured to remotely detect wind speed and direction in 30 range gates, from 163 meters ASL to 1789 meters ASL in the vertical. Vertical resolution for each gate is 60 m. When profiler data are compared to in-situ methods of determining wind speed and direction, a rawinsonde for example, agreement has been cited to be within $\pm$ 2.5 m/s (Weber and Wurtz 1990). The RWP determines the wind speed and direction as a function of antenna beam positioning, backscatter from wind advected turbulence-size irregularities in the index of refraction, Doppler theory, and signal processing. The RASS determines virtual temperature by using the RWP to measure the speed of sound. A 24 hr time series represent the culmination of this data (Fig. 14).

This seems an appropriate time to explain how wind direction is indicated in the profiler time series figures, the first of which will be used in chapter V (Fig. 13). Additionally, wind speed and vertical mixing height will be explained since they will be discussed in the chapter VI. The wind barbs from the surface to 5000 ft indicate the wind direction, every 30 minutes, over the 24 hr period. Barbs pointing towards the right (left) are westerly (easterly) winds. The small clear centered dots indicate

winds less than five knots and their direction is not graphically represented. Those pointing to the top (bottom) are southerly (northerly) winds and all of these wind barbs also indicate wind speed. For example from 1000 through 1600 PST at 1000 ft, there is a definite sea breeze from the west from five to 15 knots, (Fig. 14). Additionally, this sea breeze affects the vertical mixing height.

The black vertical lines connected by two horizontal lines, that oscillates in the vertical of Fig. 13, is the profiler derived vertical mixing depth. This is calculated using surface temperature observations that are lifted dry adiabatically until they become negatively buoyant, which is represented by the lower horizontal black line or lower mixing height, (Nuss 2003). The upper horizontal line or upper level mixing height is estimated by adding one degree Celsius to the parcel temperature.

A. PROFILER THEORY AND OPERATION

Three electro-magnetic (EM) transmission/reception paths or beams emanate upward from the phased-array antenna of the surface based NPS RWP. The RWP emits pulses of EM energy along each of these beam paths, one at a time, and "listens" for backscatter at discrete time intervals of 400 nanoseconds. This process occurs on the order of a few milliseconds and sampling continues for 30 seconds on beam, then the sampling switches to the next of the three beams, and continues for 26 minutes in efforts to attain the best representation of the U, V, and W wind components above the profiler.

Backscatter can be caused by inhomogeneities in the atmosphere's index of refraction, hydrometeors, or non-

atmospheric related backscatter sources (e.g., bugs, birds, aircraft, etc). The inhomogenities in the atmosphere's index of refraction are caused by temperature and humidity fluctuations in the atmosphere. Humidity fluctuations are roughly four times as effective as temperature fluctuations in producing backscatter. Hydrometeors ranging in size from cloud-size droplets to raindrops also backscatter EM energy from the RWP.

All of these scatterers that are advected by the wind reveal the speed and direction of the wind though Doppler theory. If the emitted EM pulse encounters relative motion between the source and the target, the backscattered EM frequency measured by the RWP receiver will be shifted, creating a Doppler shift. This frequency shift is proportional to the relative radial velocity between source and target. Wind speed is resolved based on the geometry of the beams and radial velocities

B. RASS THEORY AND OPERATION

The Radio Acoustics Sounding System (RASS) works in conjunction with the RWP and provides vertical profiles of virtual temperature, an essential parameter in determining burn prescription mixing heights. The RASS consists of four high-powered (~2000 Hz) acoustic sources oriented around the base of the RWP that emit sound for four minutes after the 26 minute wind component samplings. Through the measurement of the velocity of the acoustic wave fronts produced by the 2000 Hz sources, the RASS can determine the speed of sound, c, and the corresponding virtual temperature, Tv, using the following approximation, $Tv = (c/(20.047))^2$ (May et al 1990).

C. ATMOSPHERIC EFFECTS ON THE PROFILER AND THE RASS

The profiler and the RASS measure irregularities in the refractive index of the atmosphere. Any changing atmospheric conditions or changes in its refractive index can dramatically affect the performance of both pieces of equipment. Reduction in the detection of winds or large "holes" in data at upper ranges are usually the result of weak scattering conditions. The atmospheric conditions that can affect the performance of the profiler and RASS are as follows: humidity, turbulence, precipitation, high winds, and temperature. The Radian Corp Training Guide (1994) provides a comprehensive review of these conditions.

1. Humidity

The higher the humidity or moisture content in the atmosphere the more likely backscattering will be detected. This is due to moist air having larger index of refraction variations to backscatter interrogating EM and acoustic wavefronts. This is not the case for dry air. Dry air has smaller variations in the index of refraction and backscattering is reduced. This can result in "holes" in the wind component data. For these reasons, profilers are ideally suited for a marine environment where there is usually ample moisture. Similarly, the RASS performs well in an atmosphere with high humidity due to there being less attenuation of the transmitted acoustic wave.

2. Turbulence

More turbulence in the atmosphere means a greater chance of backscatter occurring and reaching the profiler. This is especially true for turbulence that is on the length scale of one-half that of the emitted profiler wave (~17 cm), promoting Bragg scattering. This is not

necessarily true for the RASS. Higher turbulence can disrupt the coherence of the acoustic wavefront used for temperature measurement and can reduce the obtained range.

3. Precipitation

Precipitation such as rain, snow, and hail all backscatter EM signals greater than clear air. Because of this the profiler will have a propensity to track the stronger returns instead of the clear air turbulence. The precipitation traveling at a different rate and direction than the wind will cause the winds to be erroneously determined. The RASS is unaffected by precipitation.

4. High Winds

High winds are not directly detrimental to the profiler, but the debris from objects flying through the air can exhibit excessive Doppler signal. This can overwhelm the system's ability to screen these items out and thus will calculate inaccurate winds. Increasing ground clutter can create incorrect vertical velocities used for temperature correction and can reduce the range of the RASS by displacing the acoustic signal away from the profilers beams.

5. Temperature

The RASS is more susceptible to temperature than the profiler. Acoustic waves are attenuated the most in cold dry air. Very cold or warm air propagates acoustic signals better resulting in improved range for virtual temperature measurements.

D. THE MODEL

In order to establish a relationship between the synoptic-scale model winds to the averaged profiler winds, a level of comparison had to be established. This level would have to be low enough to objectively represent the winds in the lowest 1500 feet of the atmosphere yet simultaneously be high enough to be free of the influences of the surface. A second requirement was to use model 24, 48, and 72 hr forecasts and analyses such that this information could be validated against corresponding analyses and averaged profiler data.

Only the 0000 UTC and 1200 UTC model forecasts and analyses were archived and available during 2000 to 2002 burn seasons. The 1200 UTC forecast and analyses data were chosen because they produced larger forecast verification percentages when verified with the profiler average wind flow. This is discussed in greater detail in chapter five.

Wind direction forecasts and analyses were subjectively determined using a composite of four AVN model fields during the three burn seasons. The mean sea level pressure, the 850 mb winds which are at a height of 1500 m or 5000 feet over Fort Ord, 850 mb isotachs, and 500 mb geopotential height fields were concatenated into a composite figure represent which represented the synoptic scale pattern associated with wind flow over Fort Ord. These flow directions were then entered into an EXCEL spreadsheet for filtering. Only the burn season months of September through December were examined due to the very limited burn day occurrence during July and August over the three year period.

The global spectral, hydrostatic AVN model utilized from the fall of 2000 through 2002 had increasing vertical and horizontal resolution during the 2000-2002 burn seasons. Horizontal resolution increased from T170 on 01 November 2002 to T254. Vertical resolution of the model increased from 42 unequally spaced vertical sigma levels, (12 below 800 mb) to 64 levels (15 of below 800 mb) out to 84 hours prior to 05 March 2002. AVN was run four times a day with resolution of T170 out to 180 hrs (NCEP 2003).

The resolution of the gridded model data examined extended from 32^{o}N to 42^{o}N and 130^{o}W to 114^{o}W, representing California and a portion of the eastern Pacific Ocean. The grid resolution increased during the three year period from 2.5 degree latitude and longitude for 2000 to 1.0 degree latitude and longitude resolution for 2001 and 2002. The impact of these resolution changes on forecast performance was not examined in this study and is assumed to be rather minimal.

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IV. DATA ANALYSIS AND RESULTS

Improving our ability to forecast the three burn prescription parameters at 24, 48 and 72 hr durations over the Fort Ord area was the desired objective of this study. The three parameters of offshore wind flow, five miles per hour average minimum wind speed, and a minimum lower mixing of 1500 ft ASL, all occurring simultaneously are necessary to meet the burn prescription. Additionally, due to the cost that the burn contractor incurs by being required to notify the public and stage equipment 72 hrs prior to the burn, knowing the 72 hr forecast false alarm rate is acutely important to minimize costs. Because of this 72 hr requirement, synoptic NCEP AVN model forecasts and analyses were chosen for the study. To establish a quantitative burn prescription parameter forecast verification baseline, this study focused only on the forecast skill of offshore and onshore wind flows over the Fort Ord area.

A. DATA ANALYSIS

The analysis examines the occurrence and forecast accuracy for offshore and onshore flows from three perspectives. First, the actual number of 24, 48 and 72 hr forecasts that verify against model analyses and observations will be examined. The years that have the greatest quantitative contribution to those totals were examined. Second, forecast verification percentages were calculated to provide characteristic forecast skill. Third, the meteorology that promoted accurate forecast verification at 1200 UTC was examined to help identify high confidence patterns.

The method used to determine the verification percentage was to divide the total number of possible forecasts into the total number of offshore and onshore forecasts or analyses where the wind direction was within 45 degrees of the verifying analysis or profiler observation. If the wind direction between the forecast and analysis or observation exceeded 45 degrees, the forecast was considered to not verify. These missed offshore or onshore wind forecasts are represented as false alarm rates and are equal to the corresponding verification percentage subtracted from 100.

Three years, 2000-2002, of model and profiler data were collected to assess forecast performance. Archived 1200 UTC model forecasts and analyses were subjectively examined to determine the direction of the 850 mb wind field above Fort Ord. The 1200 UTC model runs were chosen because they had the best representation of the synoptic field during the time of day when local effects, a sea or land breeze for example, had minimal impact. Corresponding profiler data was then examined to determine which forecasts the subjectively determined winds at 850 mb were within 45 degrees of the profiler winds below 1500 ft. This examination was conducted through the construction of two distinct spreadsheets, one that filtered NCEP global model fields and the other profiler data.

The profiler spreadsheet, which was created through the importing of text files downloaded from the profiler, utilized EXCEL macros to construct and concatenate data into 24 hr increments. These initial 24 hr spreadsheets calculated the burn prescription parameters of wind direction from U and V wind components derived from the profiler and surface wind anemometer observations.

Measurements were made in 30-minute intervals, from the surface to 1500 meters. From these, the average wind direction was calculated from the surface, 51 meters ASL, up to 459 meters ASL. These 30 minute wind directions were concatenated into 24 hr spreadsheets, then into six-month intervals from July to December, which represent an annual burn season. In addition to wind direction and wind speed, this first spreadsheet also included RASS derived virtual temperature measurements, which were used to calculate corresponding air parcel buoyancy characteristics, or the lower and higher mixing heights. This complete assessment of favorable burn parameters was done to determine the climatology of favorable burn days. However, only the wind direction information was compared between the two spreadsheets to assess model forecast performance.

The same three years, 2000 through 2002, were utilized to create a second spreadsheet. It contained averaged wind direction observations from the surface to 1500 ft above the NPS profiler and the subjectively determined 850 mb wind direction from forecasts and analysis above Fort Ord. Subjective interpretation of the synoptic scale fields and their corresponding effect on the 850 mb wind direction over Fort Ord was done using a composite plot of model fields; 850 mb winds, 850 mb isotachs, mean sea level pressure, and 500 mb geopotential heights.

The data in the second spreadsheet was then filtered to calculate verification percentages and construct plots of 24, 48, and 72 hr forecasts for offshore and onshore flows. Offshore flow is defined as wind directions greater than 350^{o} but less than 190^{o} and onshore flow is defined as wind directions from 191^{o} to 349^{o}. Additionally analysis

verification percentages were calculated by comparing the model analyses to the profiler observations. Examples of the meteorological conditions were then examined to help illustrate the kinds of synoptic and local conditions that could have promoted the particular verification percentages.

B. FORECASTS VERIFIED BY ANALYSES

The total possible number of offshore directed 24, 48, and 72 hr wind forecasts from 2000 through 2002 that verified within 45 degrees of the corresponding analyses ranged from a maximum of 121 to a minimum of 86 (Fig. 3). Out of the 121 three year total 24 hr forecasts that verified, the year 2000 contributed 60. The years 2001 and 2002 contributed 33 and 28 additional 24 hr forecasts that verified, respectively. The 48 hr forecasts that verified were biased towards the year 2000 data as well, with 55 out of a total 107 forecasts from that year. The 48 hr forecasts from 2001 and 2002 provided an additional 29 and 23 of the forecasts that verified, respectively. The 72 hr forecasts demonstrated the same trend. The 2000 burn season contributed 44 72 hr forecasts that verified out of the 86 total. Only 26 of the total number of 72 hr forecasts that verified came from the 2001 and 16 from the 2002 burn seasons. This examination shows:

1. Offshore flow occurs more frequently and is forecast at shorter durations, particularly in 2000.

2. There can be a large year-to-year difference in the frequency of offshore flow forecasts and events.

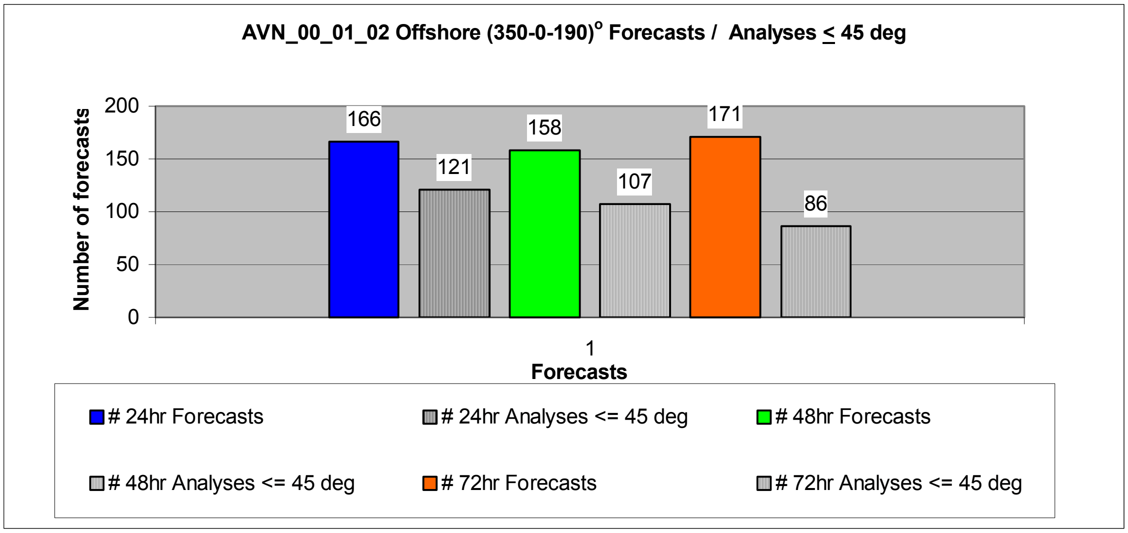

FIGURE 3. Total number of offshore flow 24, 48, and 72 hr forecasts and those that verified within 45 degrees of analyses

This year-to-year model variance is reflected in more offshore flow forecasts in 2000 than the other two years. This dominance of year 2000 forecasts in offshore forecasts that verified is not demonstrated in the onshore flow forecasts.

The cumulative number of onshore 24, 48 and 72 hr forecasts that verified within 45 degrees of their corresponding analyses ranged from a maximum of 146 to a minimum of 108 (Fig. 4). The 24, 48, and 72 hr onshore flow forecasts that verified within 45 degrees were equally represented by all three years, with 2001 demonstrating a slightly greater contribution. The 2001 data provided 55 24 hr forecasts that verified while the years 2000 and 2002 contributed 43 and 48 forecasts, respectively to the 146 total.

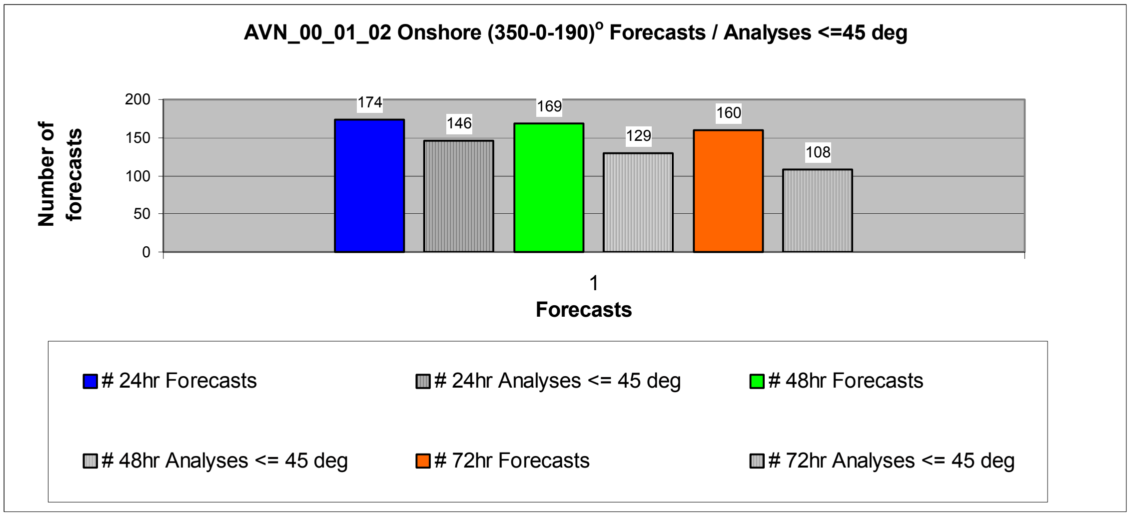

FIGURE 4. Total number of onshore flow 24, 48, and 72 hr forecasts and those that verified within 45 degrees of analyses.

2001 data provided 48 forecasts to the three-year total number of verifying 48 hr forecasts of 129. The year 2000 contributed 35 forecasts and 2002 contributed 46 48 hr forecasts to the 129 three-year total. Lastly, 2001 provided 46 of the 108 72-hr forecasts that verified. The year 2000 contributed 33 forecasts and 2002 a slightly lower 29 to the 108 three year forecast total. This examination displays several points that are worth noting;

1. Onshore flow forecasts and events were handled better than offshore forecasts.

2. Onshore flow is more frequently correctly forecast at shorter forecast durations, as is offshore flow.

3. Onshore flow did not display large year to year difference in frequency of forecasts and events.

Although the raw verification numbers provide insight into forecast performance and its year to year variation, the forecast verification percentages for the 24, 48, and 72 hr

forecasts were calculated for offshore and onshore flows to provide a characteristic performance measure.

Offshore flow verification percentages graphically represent the number of times that the forecasted flow at 850 mb above Fort Ord was within 45 degrees of the corresponding analyses (Fig. 5).

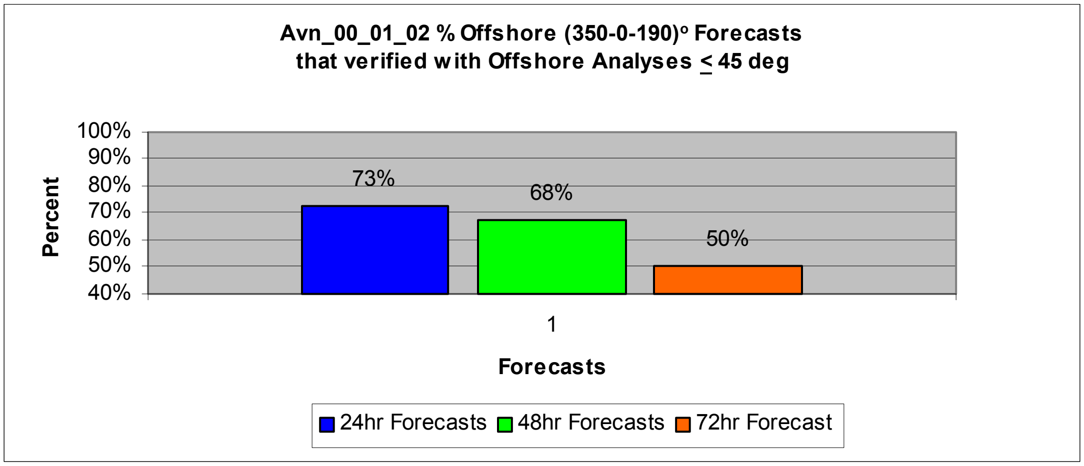

FIGURE 5. Offshore flow 24, 48, and 72 hr forecasts verified by analyses, verification percentages

This demonstrates a decrease in forecast skill with increasing forecast duration and is typical of most meteorological predictions. The 24 hr forecasts verified with the corresponding analyses 73% of the time. This prediction percentage decreases to 68% when examining the 48 hr forecasts and to 50% for 72 hr forecasts. The implication of the results in Fig. 5 are that if the model indicates offshore flow that is favorable to support burn conditions, then at least half of the time those conditions will occur even when using a 72 hour forecast (Nuss 2003).

Figure 6 demonstrates how onshore flow forecasts decrease in forecast skill with increasing forecast duration.

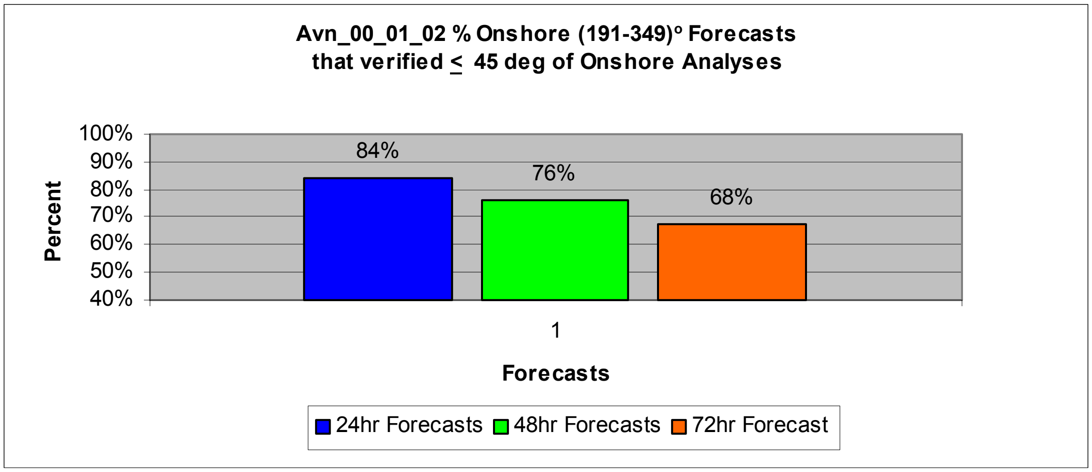

FIGURE 6. Onshore flow 24, 48, and 72 hr forecasts verified by analyses, verification percentages

Offshore forecasts demonstrate this same trend, but verify on average 10% better than offshore flow forecasts, regardless of forecast duration. The 24 hr forecasts predicted onshore winds within 45 degrees of the analyses 84% of the time. The 48 hr forecast verification percentages decreases to 76% and the 72 hr to 68%. The implication of these results are that if the model indicates onshore flow, then at least two thirds or 66% of the time those conditions will occur even when using the 72 hr forecast. These offshore and onshore verification percentages seem straightforward but there are a few additional points that should be mentioned. The first is that this was a measure of raw model performance against its analysis, which can differ from actual flow and will be addressed next. Secondly, synoptic conditions favorable to generate offshore flow are more poorly forecast than onshore flow, which is climatologically favored. Lastly, the 45 degree verification range is very generous and may exceed allowable tolerances.

C. FORECASTS VERIFIED BY PROFILER OBSERVATIONS

Recall that the two levels of wind direction being compared are not identical. The model flow is a subjective direction 5000 ft above Fort Ord and the profiler flow is an average direction from the surface up to 1500 feet. This difference in levels being compared is not ideal but is representative of the performance of a synoptic forecast in assessing local conditions. Forecast verifications between the model and profiler are illustrated in Fig. 7 and Fig. 8.

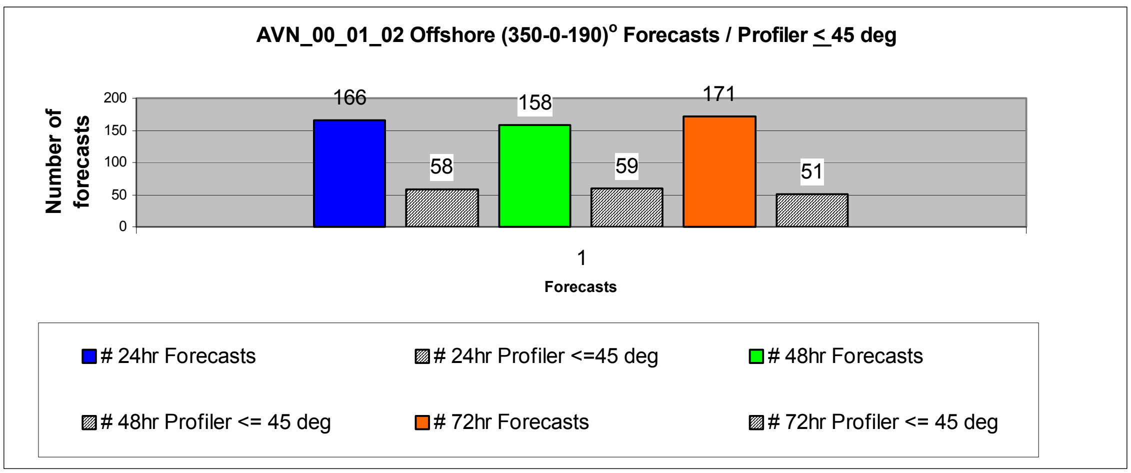

FIGURE 7. Total number of offshore flow 24, 48, and 72 hr forecasts and those that verified within 45 degrees of the profiler.

The total number of 24, 48, and 72 hr offshore flow forecasts that verified against the profiler ranged from a minimum of 51 to a maximum of 59 (Fig. 7). All three forecast durations 24, 48, and 72 hr had roughly a 50% contribution from the 2000 burn season to the three-year totals. The 24 hr forecasts verified by the profiler received the majority of their forecasts from the 2000 season, with 28 forecasts. The 2001 and 2002 burn season contributed 17 and 13, 24 hr forecasts, respectively. The

number of 48 hr forecasts that verified from 2000 was 32, where 2001 and 2002 provided 16 and 11, 48 hr forecasts to the 59 forecast total. The 72 hr forecasts demonstrated a similar trend, with 22 from 2000, 16 from 2001, and 13 from 2002 for a cumulative total of 51.

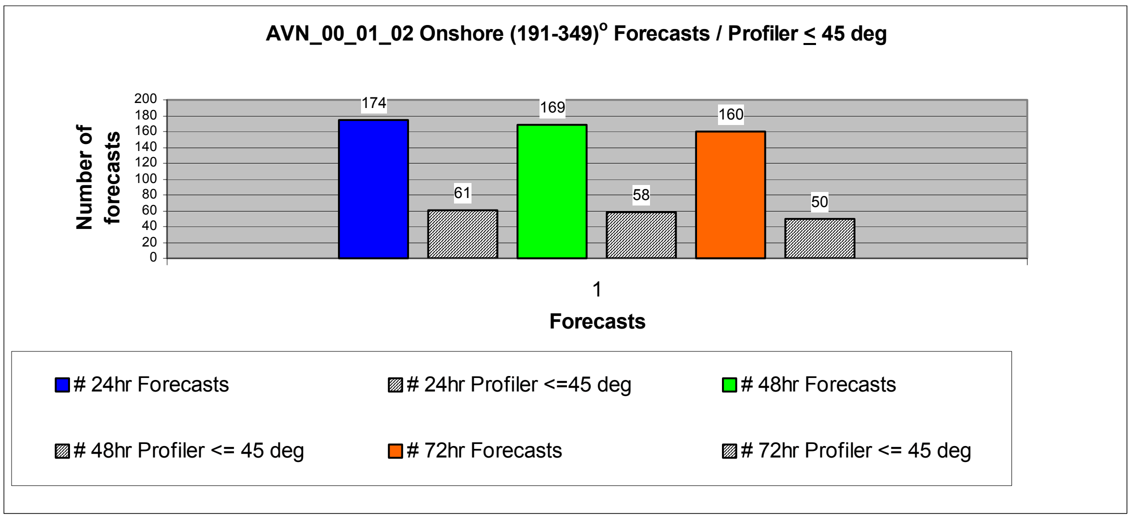

FIGURE 8. Total number of onshore flow 24, 48, and 72 hr forecasts and those that verified within 45 degrees of the profiler.

This dominance by the year 2000 data is not represented in the onshore flow forecast data, (Fig. 8). All three years of forecasts, at all durations, contributed fairly equal to the onshore flow cumulative forecast totals. The majority of 24 hr forecasts that verified were from 2001, making up 39% of the three year total. The years 2000 and 2002 provided 19 and 18 forecasts, respectively, to the 61 total 24 hr forecasts that verified, which represented 31% and 30% of the cumulative total. The 48 hr forecasts again were slightly dominated by the 2001 data. Only 22 of the 58 cumulative forecasts came from 2001, creating a 37% contribution. Years 2000 and 2002 provided only 17 and 19 forecasts, respectively.

However, the 72 hr onshore flow forecast three year cumulative total was slightly dominated by 2000 data, providing 20 of the 50 forecasts for 40% of the total. Here, 2001 makes up 19 of the forecasts with 2002 only 11. Both onshore and offshore flows performances demonstrated similar numbers of verified forecasts illustrating a kind of flatness in performance, as seen in Fig. 7 and Fig. 8. The corresponding verification percentages were calculated for offshore and onshore flows as well to demonstrate the forecast performance compared to actual observations.

The percentage of 24, 48, and 72 hr offshore flow forecasts that verified by the profiler is represented in Fig. 9. It can be seen that forecast verification does not vary significantly with forecast duration and all durations verify less than 40% of the time. These consistently low verification percentages are also found when examining onshore flow (not shown). The synoptic conditions that produced offshore flow in the NCEP model forecasts do not

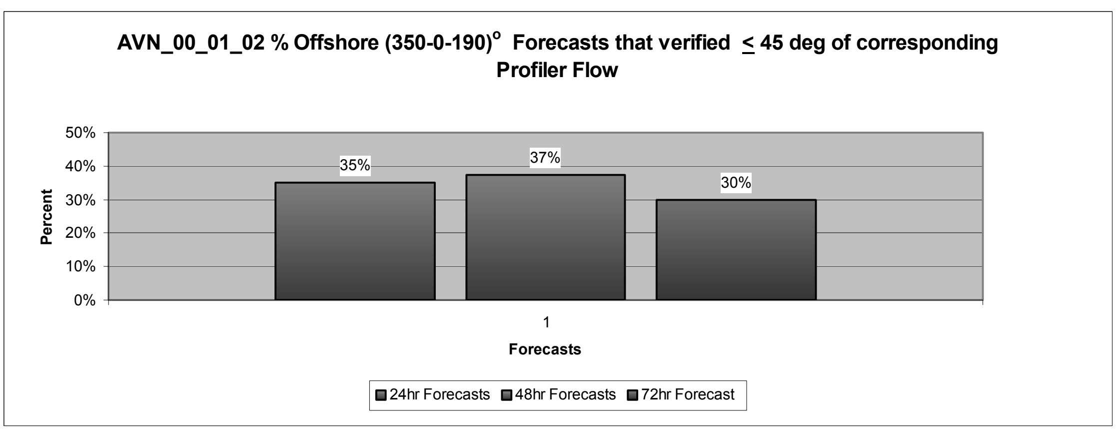

FIGURE 9. Offshore flow 24, 48, and 72 hr forecasts verified by the profiler, verification percentages

adequately represent the local wind conditions above the profiler. For example, local mesoscale events such as sea breezes, land breezes, and synoptically induced mesoscale events are not resolved in the large-scale forecast by the synoptic scale models, due to their relative low resolution. In contrast, the profiler observation resolves only these features and only at one location. These consistently low verification percentages could also be due to comparing winds at approximately 5000 feet to winds averaged from 1500 feet down to the surface at one location.

When considering the onshore flow 24, 48, and 72 hr forecasts that verified with the profiler, the forecast verification percentages produced are almost identical in magnitude to the offshore values shown in Fig. 9. Due to these results being so similar to those representing offshore flow they were not displayed. Again, this suggests synoptic conditions resolved in the model do not accurately represent the local wind conditions at Fort Ord, as mentioned above, or maybe the comparison of two different wind levels is inadequate. This poor correlation between the local conditions and the synoptic scale can further be demonstrated through comparing the NCEP model analysis to corresponding wind profiler observations.

D. ANALYSES VERIFIED BY PROFILER OBSERVATIONS

A unique perspective was gained by comparing the profiler to the model analyses. The analyses that corresponded to available 24, 48 and 72 hr forecasts of offshore and onshore flow from 2000 to 2002, were verified against the profiler flow within 45 degrees (Fig. 10 and Fig. 11).

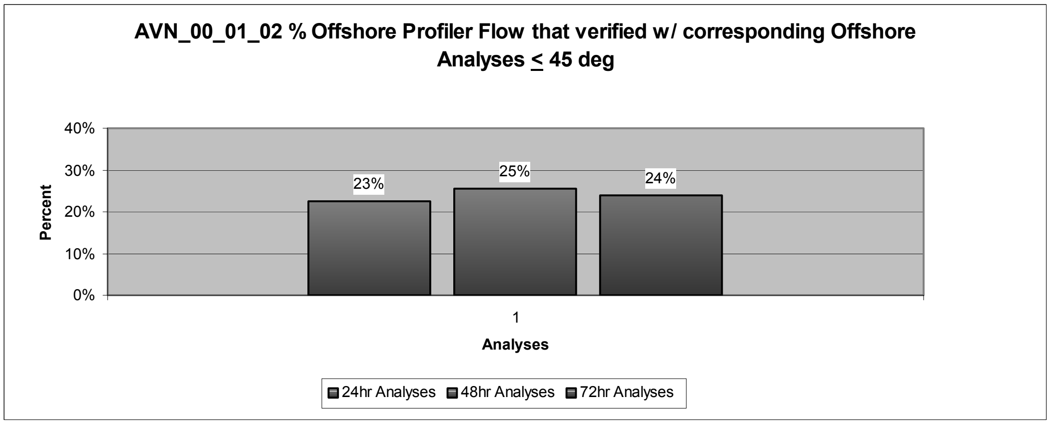

FIGURE 10. Offshore flow 24, 48, and 72 hr analyses verified by the profiler, verification percentages

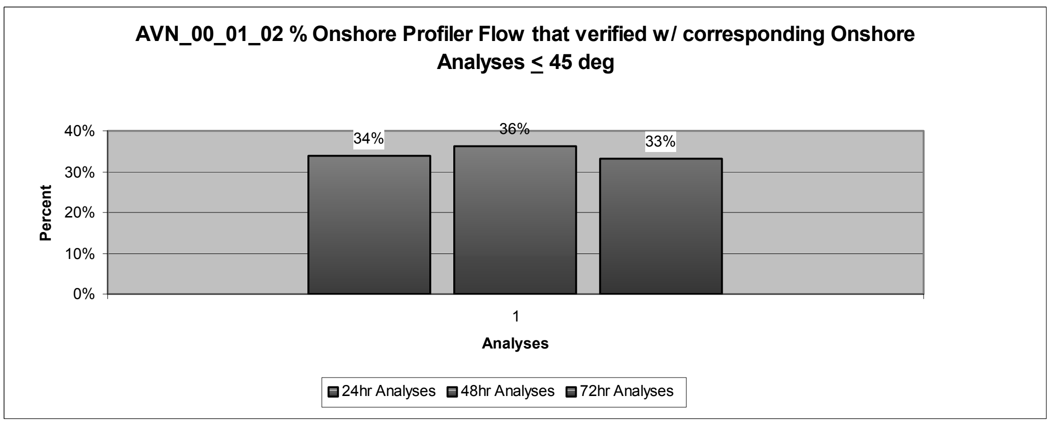

FIGURE 11. Onshore flow 24, 48, and 72 hr analyses verified by the profiler, verification percentages.

The offshore 24, 48, and 72 hr analyses verification percentages in Fig. 10 are 23%, 25%, and 24%, respectively. These numbers differ only because the sample of analyses was slightly different when selected using 24, 48, or 72 hr forecasts. Corresponding onshore analyses validation percentages are 34%, 36%, and 33%, as shown in Fig. 11. Onshore flow demonstrates a distinct 10% increase in verification over the 24, 48, and 72 hr analyses for offshore flow. Both the offshore and onshore verification percentages are consistently low and are similar in

magnitude, less than 40%. These results are impacted due to similar issues discussed previously in the forecast-to-profiler verification percentages. In this case, the lack of correspondence represents the inability of the synoptic model analyses to capture local details seen in the profiler. The difference in levels as well as scales represented results in verification percentage less than 40%. This implies that local details are a significant component to the actual flow over Fort Ord.

V. METEOROLOGICAL EXPLANATIONS OF FORECAST VERIFICATION

To understand the factors that contribute to or prevent a forecast from accurately verifying, specific examples were examined. This examination focused on determining characteristic meteorological scenarios that have a higher than average chance of verifying against the profiler, or clearly have little chance for verifying against the profiler. Insight into the meteorological characteristics that promote or hinder verification will help more properly apply synoptic-scale guidance to the localized forecast problem

A. EXAMPLES THAT INCREASED FORECAST VERIFICATION PERCENTAGES

Wind direction forecasts verified by the model analyses and those verified by corresponding profiler data provide insight about different aspects of the forecast problem. Forecasts verified by the model analyses demonstrated how model physics, parameterizations, optimal interpolation schemes, observations, initial conditions, and other parameters represented in the model results in accurate synoptic scale forecasts. This is much different than forecasts verified by the wind profiler. How the synoptic and mesoscale winds coupled over Fort Ord at the appropriate UTC time was the determining factor for verification. When verification between the model and the profiler does not occur, it suggests that local effects do not strongly correspond to the synoptic scale.

The meteorological events that occurred through the burn season (July - December) that influenced forecast

verification comparisons with the profiler can be separated into two distinct categories. First, events that verified (homogeneous or the same relative flow direction) when the 850 mb subjective model wind flow was within 45 degrees of the corresponding average profiler observations in the lowest 1500 ft above the profiler. Second, forecasts where the forecast wind flow was not within 45 degrees of the profiler (heterogeneous or wind flow > 45^o apart) but still in the same general direction (offshore versus onshore). Examples of those synoptic and mesoscale meteorological events that produced homogeneous and heterogeneous flow categories will both be examined to highlight the factors that may be important to link the synoptic and mesoscale flow patterns.

The 72 hr offshore flow forecast that verified at 1200 UTC on 23 September 2000 demonstrates offshore flow at 850 mb over the Monterey Bay area under weak synoptic forcing (Fig. 12). This is promoted by a thermal trough off northern California, with a 1008 mb surface low pressure center near Cape Mendicino. The 500 mb heights show ridging offshore that extends in to the Pacific NW and supports offshore flow over Monterey Bay.

The corresponding analysis verifies the offshore flow at 850 mb, (Fig. 13). Although the 1008 mb surface low in the 72 hr forecast does not exist, the surface pressure isobars still suggest offshore flow but not as strongly as in the forecast. The 500 mb heights increase from 5580 m in NE Nevada to 5760 m along the California coast. Additionally, the flow into and the location of the 500 mb trough supports an offshore flow component over California, potentially supporting offshore flow at 850 mb over the Monterey Bay area.

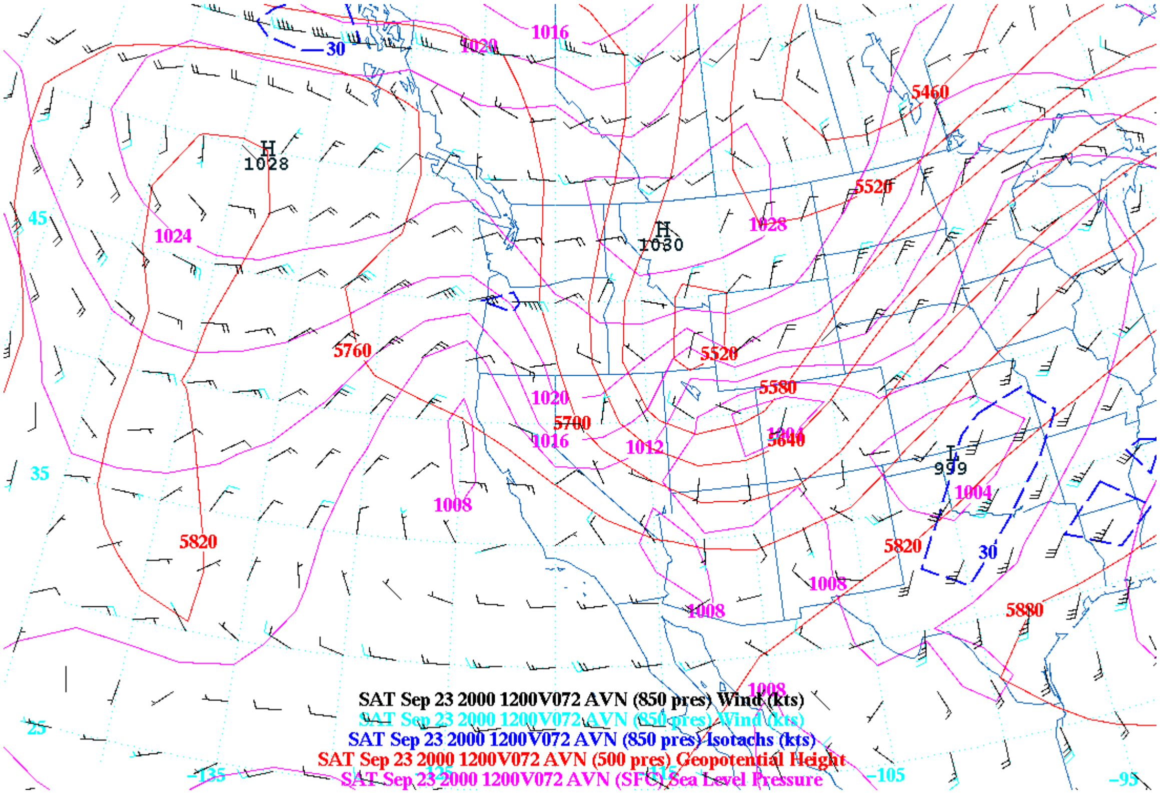

FIGURE 12. 72 hr AVN 1200 UTC offshore flow model forecast of sea level pressure (pink lines), 500 mb heights (red lines), and 850 mb winds (black barbs).

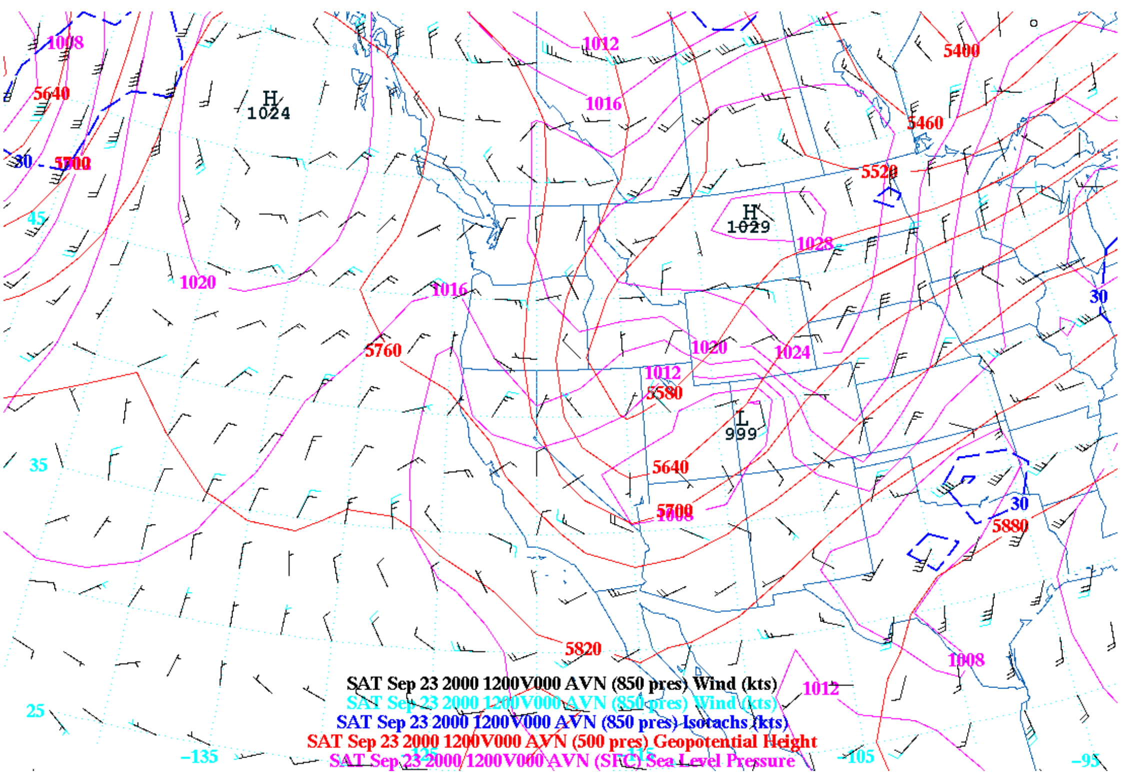

FIGURE 13. 23SEP2000 AVN 1200 UTC offshore flow analysis.

These 1200 UTC 72 hr forecast and analysis correspond to 04 AM Pacific Standard Time (PST) on the profiler time series, (Fig. 14).

Verification between the subjective synoptic offshore flow at 1200 UTC at 850 mb in the model and the analysis does verify with the average mesoscale profiler flow observation below 1500 ft within 45 degrees.

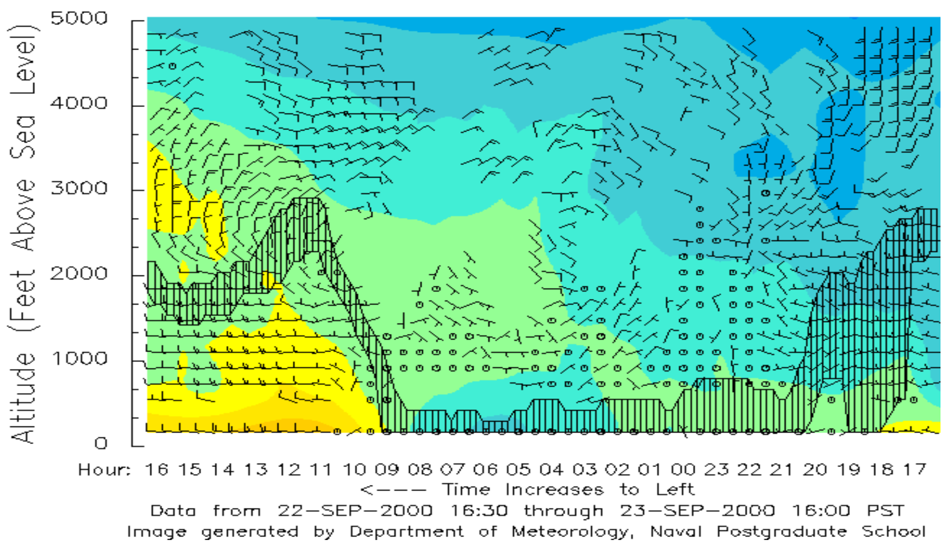

FIGURE 14. 22-23SEP2000 offshore flow profiler time and vertical section image, surface to 5000 ft winds (black barbs).

The profiler flow at 04 AM PST corresponds to a land breeze or offshore flow in the lowest 1500 ft, which is probable during this time of day due to the reversal of the diurnal thermal gradient along the coast. This type of synoptic scale offshore flow and land breeze combine to produce homogeneous flow at 1200 UTC. As seen on the profiler time series, during the seabreeze part of the cycle the low-level flow turns onshore even though offshore flow occurs aloft. Consequently, the 1200 UTC verification time is able to capture the basic flow above the 1500 ft layer.

An example of similar homogenous coupling of below 1500 ft and 850 mb during onshore flow shown in the 72 hr forecast of onshore flow at 850 mb that verifies on 16 September 2002, (Fig. 15). The onshore flow is associated with a 1025 mb semi permanent surface high in the Pacific ocean, which is a common synoptic feature during the July, August, and September. The geographic orientation of the high pressure system's anticyclonic flow relative to the California coast and promotes onshore flow over the Fort Ord area at 850 mb. The verifying analysis of the 72 hr forecast again displays the semi permanent surface high, which promotes 850 mb onshore flow over Fort Ord, (Fig. 16).

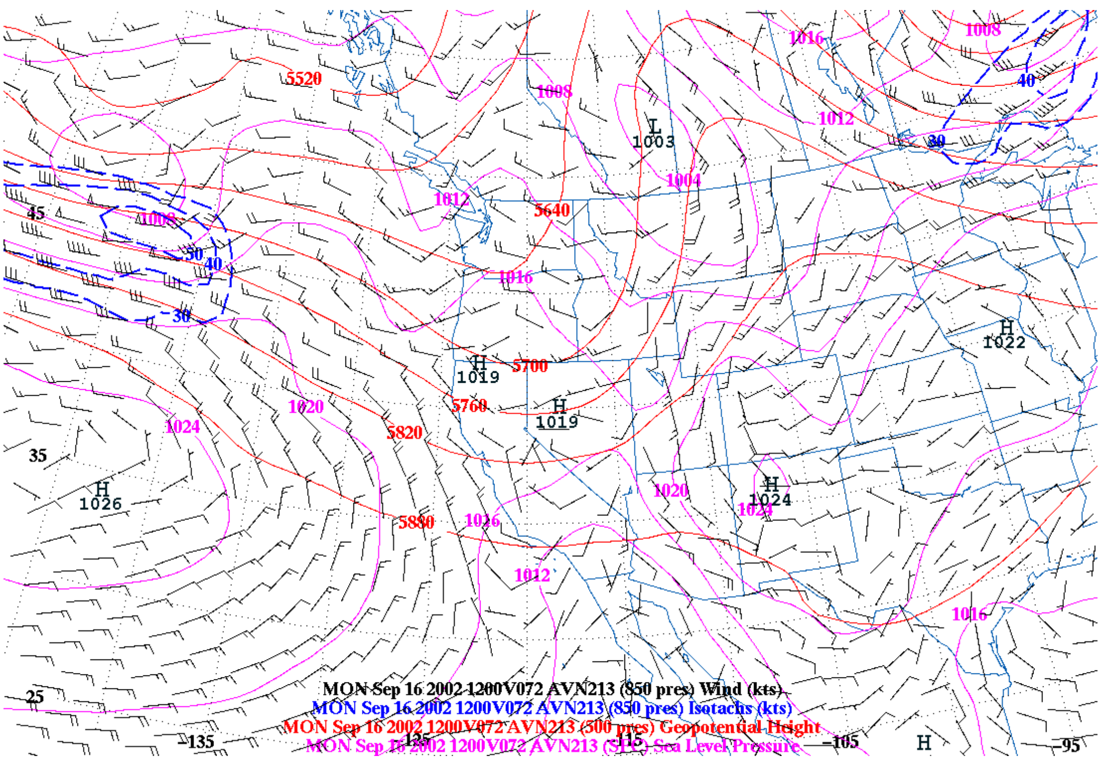

FIGURE 15. 72 hr AVN 1200 UTC onshore flow model forecast of sea level pressure (pink lines), 500 mb heights (red lines), and 850 mb winds (black barbs).

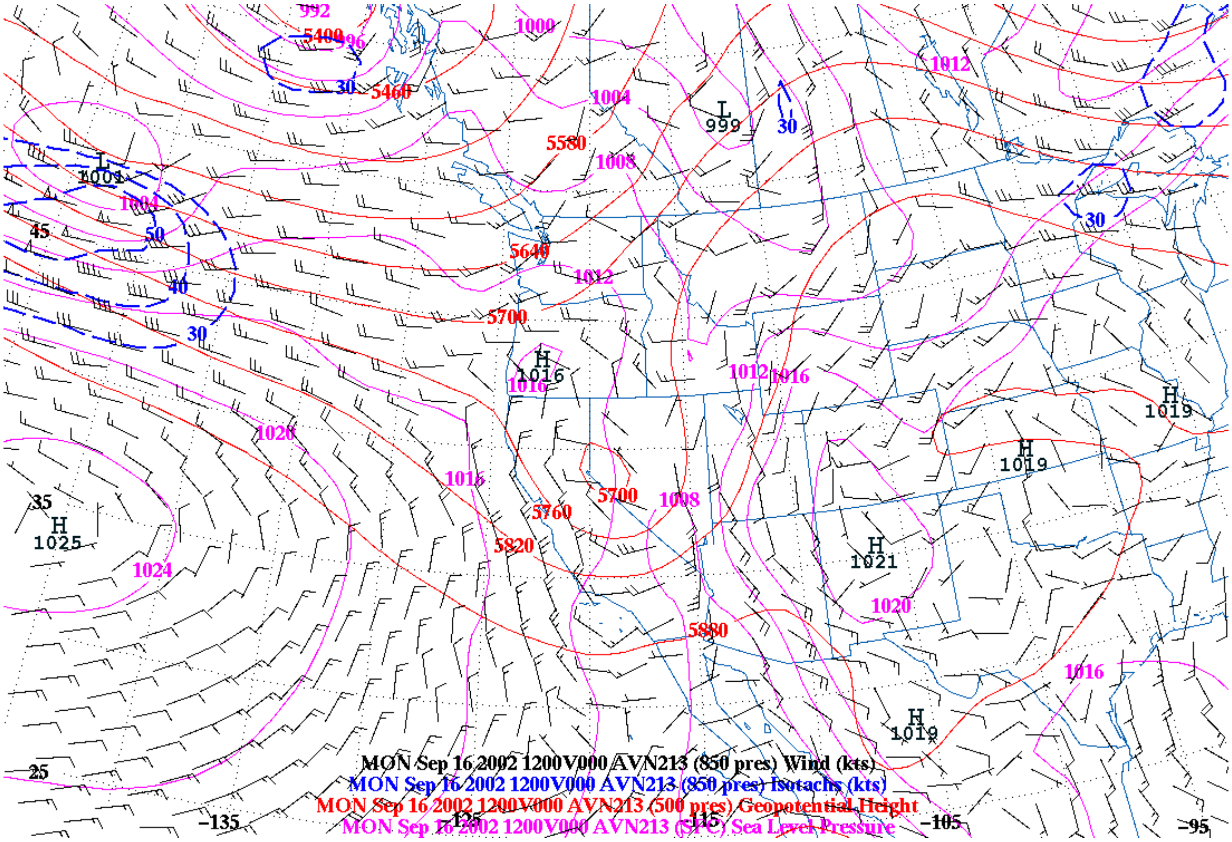

FIGURE 16. 16SEP2002 AVN 1200 UTC onshore flow analysis

The local conditions at 1200 UTC in the profiler image verify within 45 degrees of the 850 mb model flow and demonstrate onshore flow in the lowest 1500 ft, (Fig. 17). This flow may seem contradictory, since land breezes usually occur at this time of the day, however, only a very weak land breeze existed from 8-9 AM. The reason for the lack of a land breeze is the relatively strong synoptic scale onshore flow. This onshore flow example shows how synoptic scale effects combine with the mesoscale to result in correct verification (homogeneous flow) during the warmer half of the burn season. As the months advance from October, November, to December the inland areas tend to cool and synoptic scale forcing becomes stronger.

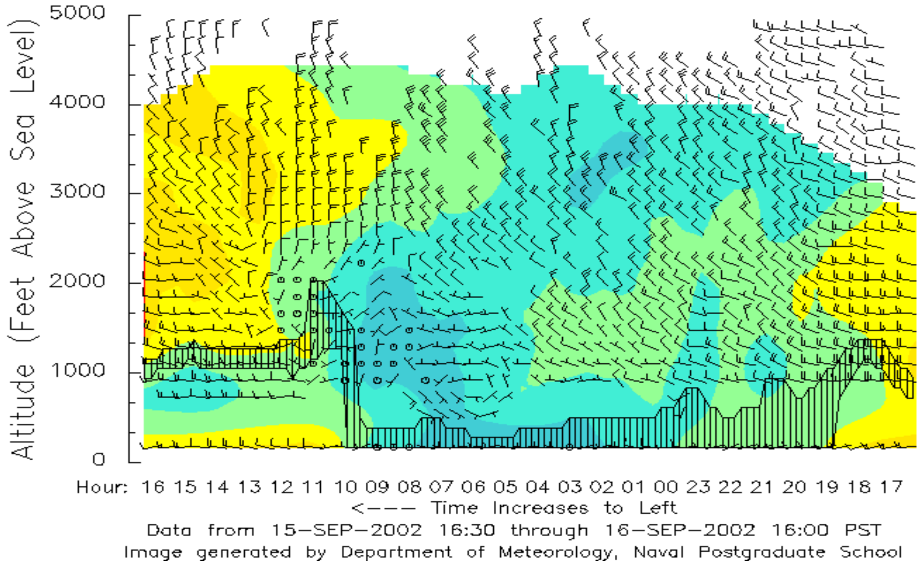

FIGURE 17. 15-16SEP2002 onshore flow profiler time and vertical section image, surface to 5000 ft winds (black barbs).

As a consequence, mesoscale land/sea breeze effects become less important when verifying forecasts against the profiler.

The synoptic situation in the 1200 UTC 72 hr forecast that verified on 24 December 2001 demonstrates weak offshore flow as a result of a weak Santa Anna wind event competing with a moderate strength extratropical (ET) cyclone off the coast of British Columbia (Fig. 18). Weak offshore flow over the Monterey Bay area at 850 mb is associated with anticyclonic flow of the 1040 mb surface high over NE Nevada extending into Utah, Idaho, and Oregon that is flow directly against the onshore 850 mb flow due to the ET.

The corresponding analysis (Fig. 19) demonstrates that although the 72 hr forecast indicated weak offshore flow, a more distinctive offshore flow scenario actually occurred.

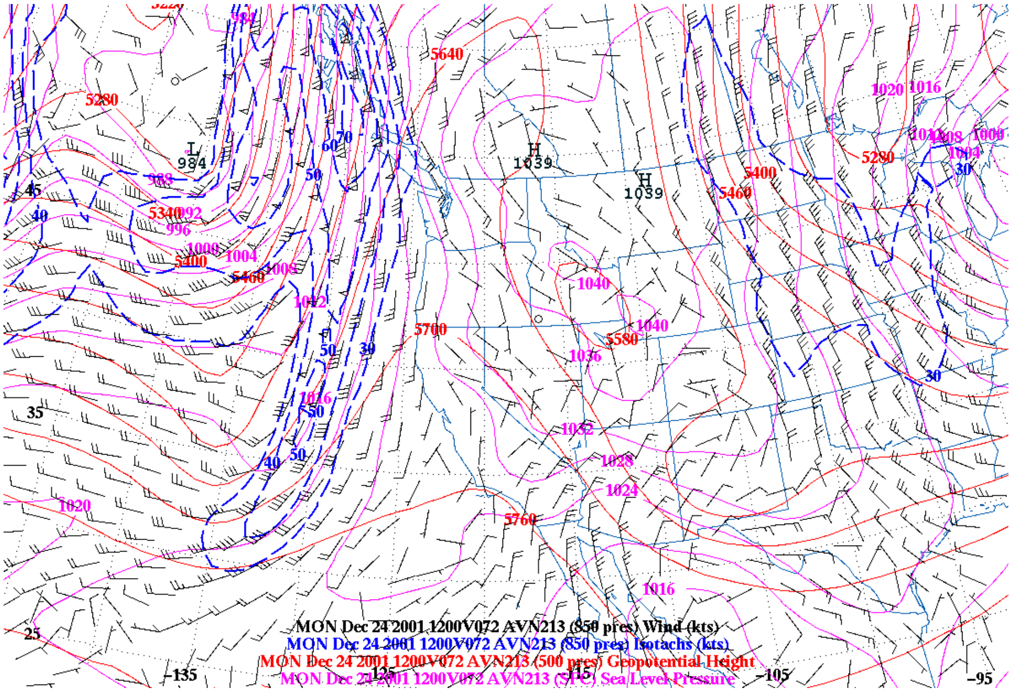

FIGURE 18. 72 hr AVN 1200 UTC offshore flow model forecast of sea level pressure (pink lines), 500 mb heights (red lines), and 850 mb winds (black barbs).

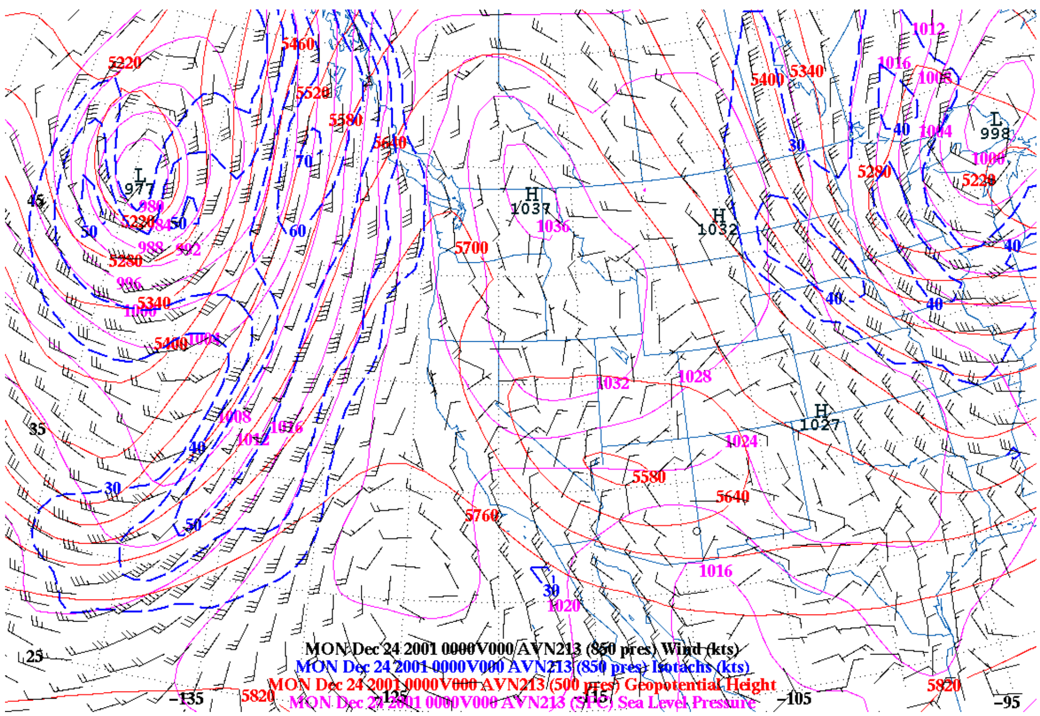

FIGURE 19. 24DEC2001 AVN 1200 UTC offshore flow analysis.

A weaker 1037 mb surface high extending over Nevada, Oregon, Idaho, and Utah promotes anticyclonic southeasterly flow at the surface over CA. The surface pressure gradient over CA is relatively the same as the forecast yet the ET in the Pacific NW has not moved as eastward as forecasted. This results in stronger offshore flow conditions over the California coast.

The profiler displays (Fig. 20) rather strong easterly offshore flow at 04 AM PST and offshore flow well above the 1500 ft layer throughout most of the day, agreeing with the 850 mb forecast and analysis within 45 degrees.

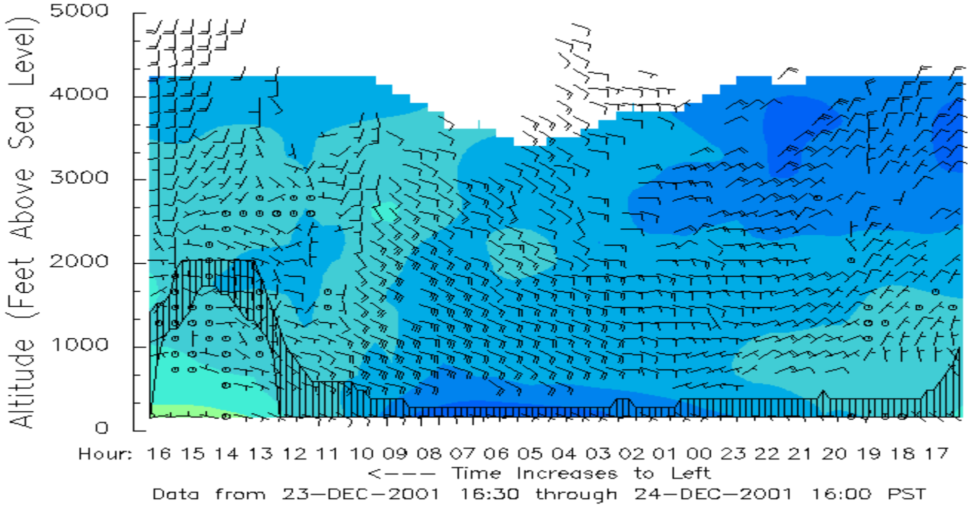

FIGURE 20. 23-24DEC2001 offshore flow profiler time and vertical section image, surface to 5000 ft winds (black barbs).

A weak diurnal coastal thermal gradient, common during late December, in conjunction with strong synoptic forcing causes the land breeze in the boundary layer to be weaker than during the first three months of the burn season. This causes them to be easily masked by stronger synoptic flow, which allows homogeneous offshore flow from the surface to 5000 ft at the profiler site.

Strong synoptic conditions can overcome local conditions and to create homogeneous onshore flow as shown by the 72 hr forecast and the verifying analysis on 08 November 2002. The 72 hr forecast and analysis show an extratropical cyclone in the Pacific NW is approaching the west coast, (Figs. 21 and 22). The 960 mb low is creating 20 to 30 kt onshore winds along the CA coast. Due to the time of year and the corresponding weak thermal gradient along the coast, the strong synoptically driven onshore flow is homogeneous from 5000 ft to the surface at 1200 UTC and throughout the day, (Fig. 23). Cases of this type are strongly dominated by synoptic forcing and generally handled reasonably well by the forecast models.

In this examination of homogeneous flow situations, where the below 1500 ft winds at the profiler tend to mirror the synoptic 850 mb winds, strong synoptic forcing tends to

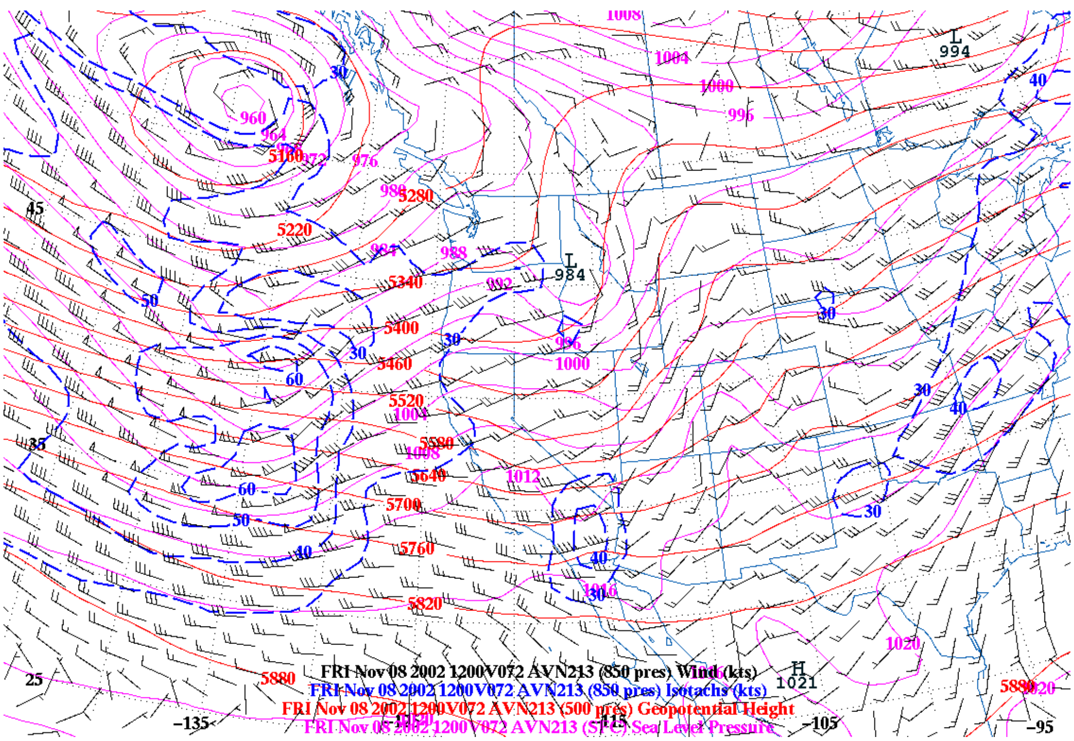

FIGURE 21. 72 hr AVN 1200 UTC onshore flow model forecast of sea level pressure (pink lines), 500 mb heights (red lines), and 850 mb winds (black barbs).

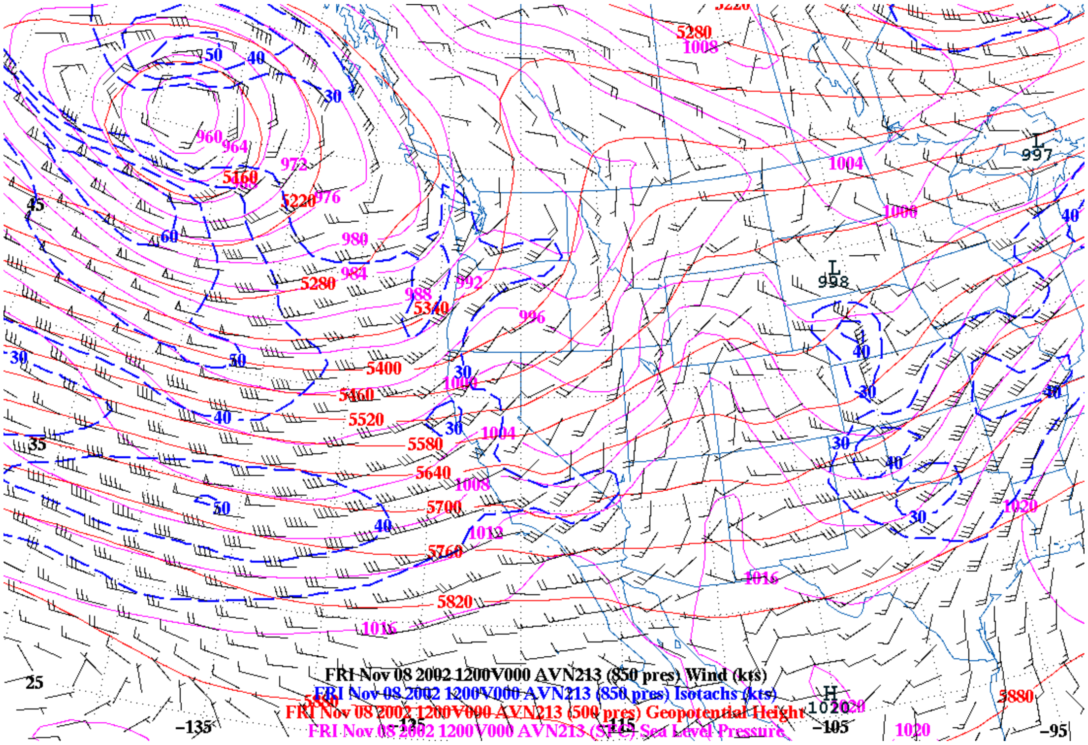

FIGURE 22. 08NOV2002 AVN 1200 UTC onshore flow analysis

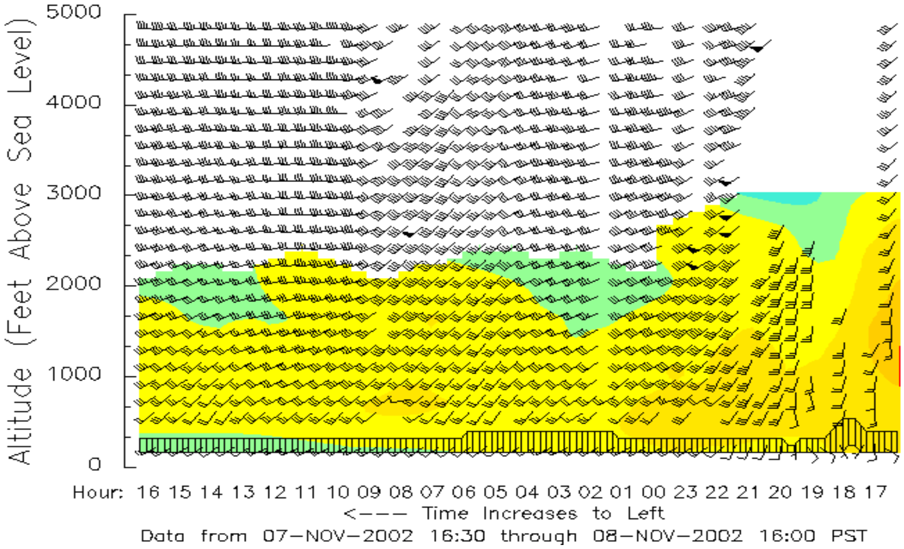

FIGURE 23. 07-08NOV2002 onshore flow profiler time and vertical section image, surface to 5000 ft winds (black barbs).

produce the necessary vertical coupling. In the earlier warm season, the more prevalent sea and land breezes are enhanced by synoptic flow from the onshore or offshore direction, respectively. Consequently, forecasts tend to verify better under stronger synoptic forcing. In the cooler part of the season, the land and sea breeze tend to be weak and even moderately strong synoptic forcing resulted in homogeneous flow characteristics. During this part of the season, the synoptic scale forecast is more reliable indication of the flow at the Fort Ord Profiler.

B. EXAMPLES THAT REDUCED FORECAST VERIFICATION PERCENTAGES

To better understand the meteorological relationships between the synoptic and mesoscale that allowed for coupling between the 850 mb flow and the low-level flow at the profiler, the synoptic and local meteorological conditions that created heterogeneous onshore and offshore flows were examined. These conditions occur throughout the burn season and represent situations where the forecast verify reasonably well in agreement with model analysis but not in agreement with profiler observations below 1500 ft. As noted in the previous section, strong synoptic forcing favors coupling and these heterogeneous cases presumably occur with weaker forcing.

The 72 hr forecast that verified on 30 September 2000, (Fig. 24), shows two distinctive yet weak, synoptic features that create weak offshore flow at 1200 UTC over the Fort Ord area. The semi-permanent high, with a 1024 mb surface pressure is located relatively far off the coast of California and the thermal low or trough, with a 1008 mb surface pressure centered over northern Mexico is displaced westward along the CA coast.

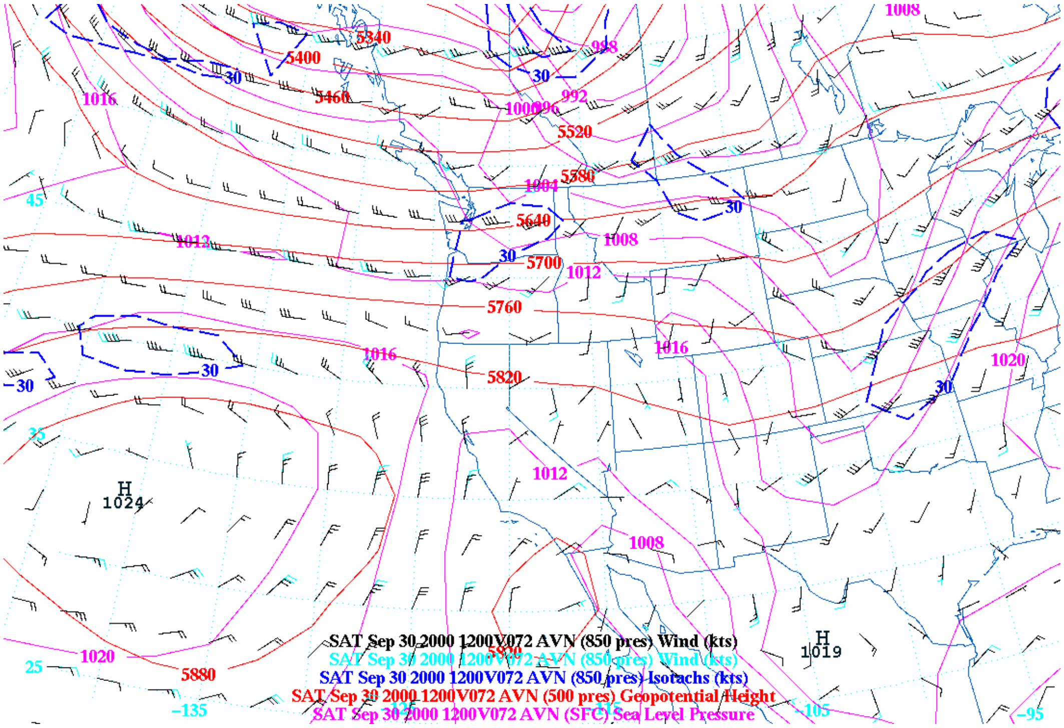

FIGURE 24. 72 hr AVN 1200 UTC offshore flow model forecast of sea level pressure (pink lines), 500 mb heights (red lines), and 850 mb winds (black barbs).

This pattern promotes weak offshore flow at 850 mb.

The corresponding analysis verifies the forecast and both of these features, (Fig. 25). The surface high in the Pacific has increased to 1025 mb and the trough axis still extends up the California coast. These two features verify and promote 850 mb offshore flow over the Monterey Bay area. However, though the model and the analysis verified within 45 degrees, the profiler did not (Fig. 26).

The 24 hr profiler image displays weak offshore flow at 04 AM PST but not within 45 degrees of the synoptic offshore flow, which is primarily northerly. The land breeze that occurs in the lowest 1500 ft is primarily easterly or southeasterly due to a strong local thermal gradient that occurs during this time of year.

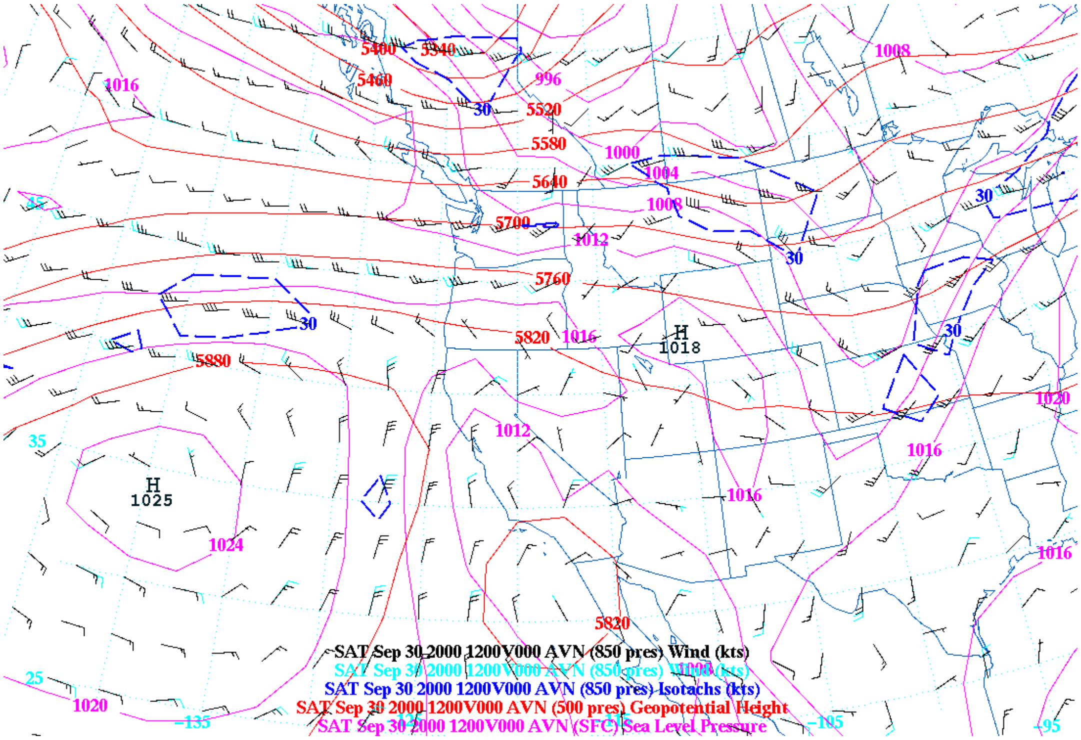

FIGURE 25. 30SEP2000 AVN 1200 UTC offshore flow analysis

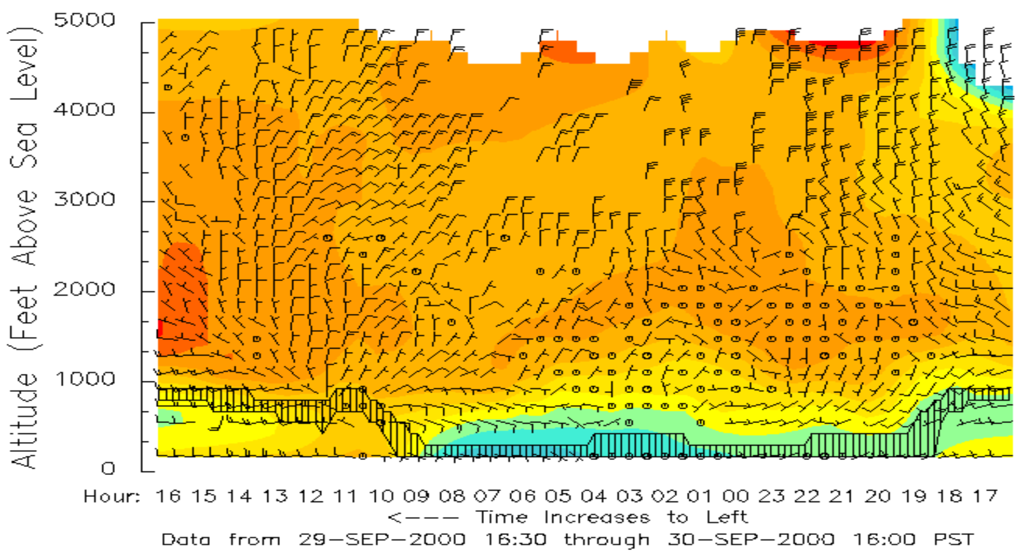

FIGURE 26. 29-30SEP2000 offshore flow profiler time and vertical section image, surface to 5000 ft winds (black barbs).

Because the northerly synoptic scale flow above does not reinforce the land breeze, there is little vertical coupling between them. Both qualify as offshore flow yet

they are not within 45 degrees of each other and thus did not increase forecast verification percentages.

The following early burn season example illustrates how the weak 850 mb onshore flow is not sufficient to overcome strong local diurnal forcing. The 72 hr forecast that verified on 05 August 2002, (Fig. 27), shows a 1016 mb surface pressure extending throughout California and into the Pacific ocean with little pressure gradient over the Monterey Bay / Fort Ord area. However, a 500 mb trough is digging down off the Pacific Northwest, creating onshore flow at 850 mb over the Monterey Bay / Fort Ord area.

The verifying analysis, (Fig. 28), shows similar surface and upper-level features as the 72 hr forecast but the analyzed features tend to be somewhat stronger.

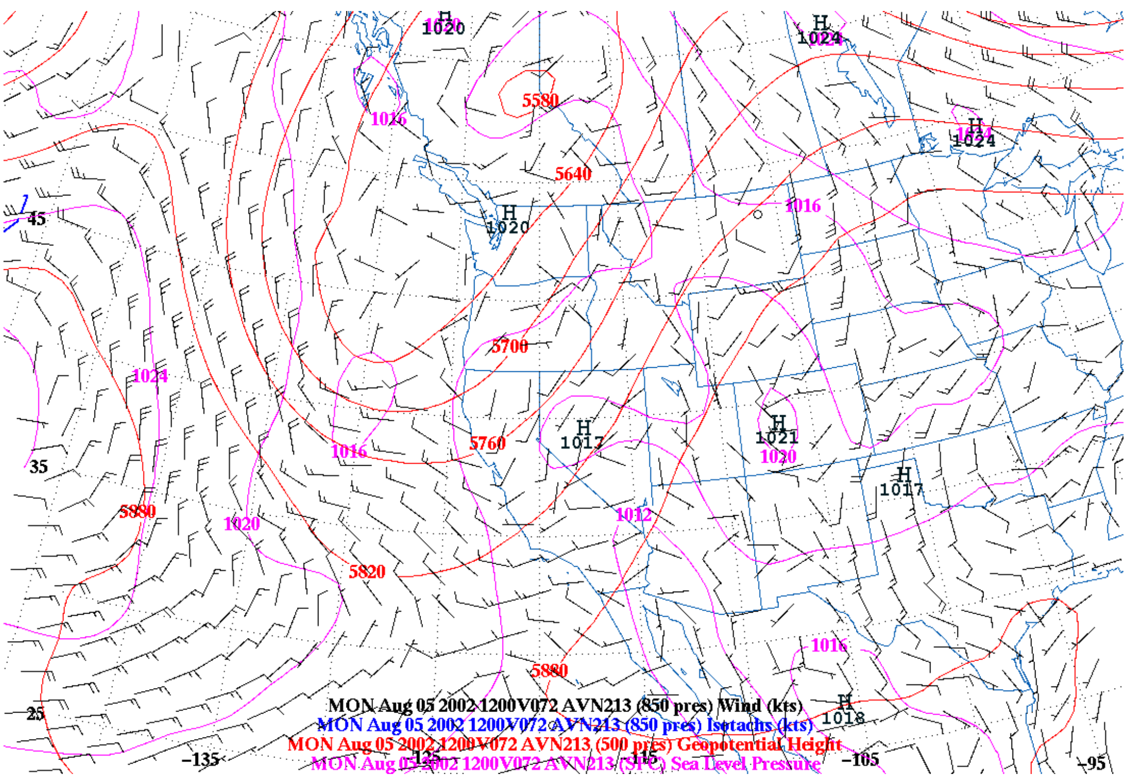

FIGURE 27. 72 hr AVN 1200 UTC onshore flow model forecast of sea level pressure (pink lines), 500 mb heights (red lines), and 850 mb winds (black barbs).

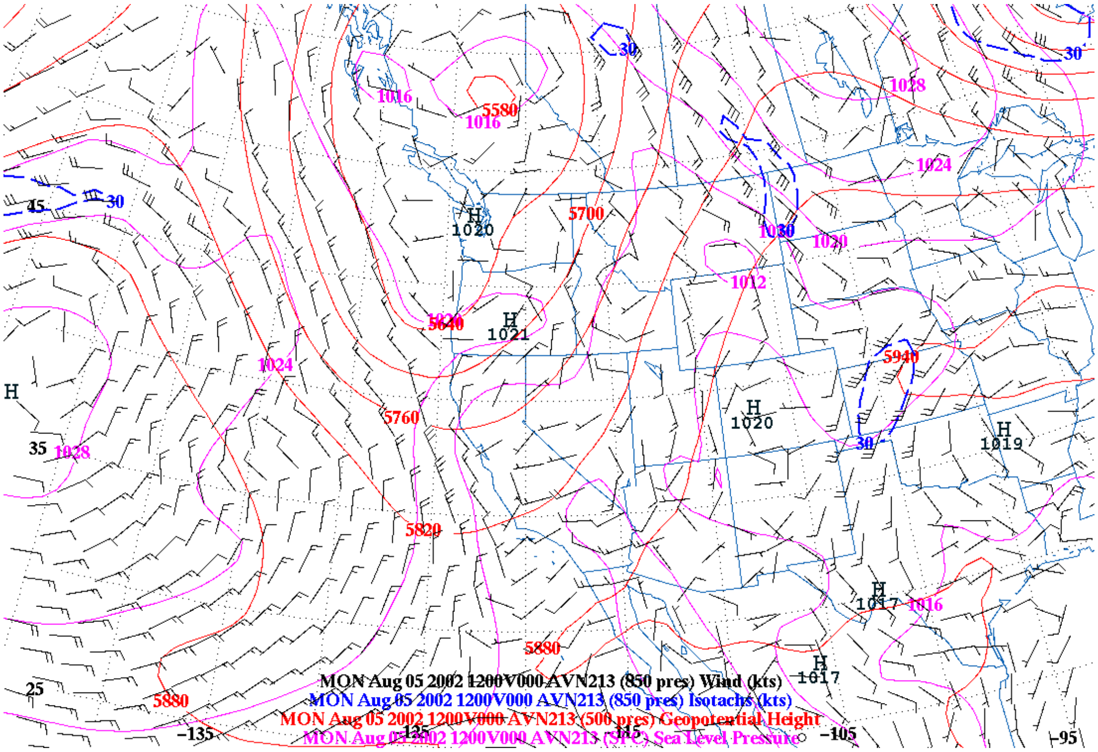

FIGURE 28. 05AUG2002 AVN 1200 UTC onshore flow analysis

The upper level trough at 500 mb creates cyclonic flow throughout the column and weak, low-level onshore flow over the Monterey Bay area. Yet, the corresponding profiler image (Fig. 29) demonstrates the effects of the weak synoptic scale onshore flow was not strong enough to eliminate the land breeze from the surface to 1500 ft.

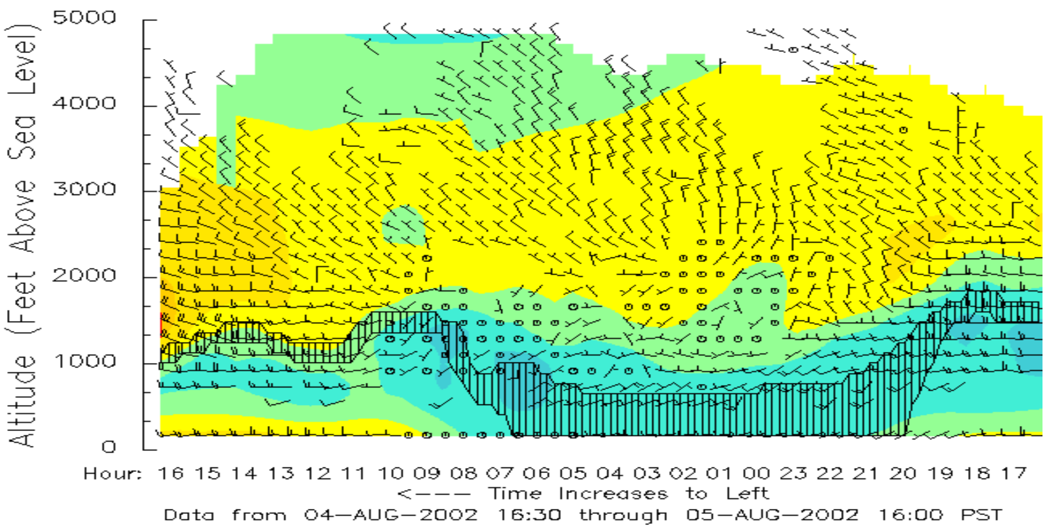

FIGURE 29. 04-05AUG2002 onshore flow profiler time and vertical section image, surface to 5000 ft winds (black barbs).

The profiler shows weak onshore flow above 800 ft at 4AM (1200 UTC) but the lowest levels capture a rather strong offshore flowing land breeze. In this case, the synoptic scale onshore flow was not strong enough to overcome the land breeze. Finally consider a heterogeneous flow situation that can occur with strong synoptic forcing during the early burn season.

The strong synoptic forcing creates significant onshore flow situation into the Monterey Bay area on the 72 hr forecast from an extratropical cyclone off the west coast of Canada, (Fig. 30). The strong vertically stacked cyclonic system has a surface pressure of 970 mb and is creating 25 to 35 knot winds from the west into the Monterey / Fort Ord area, just ahead of a cold front moving south along the coast. The verifying analysis, (Fig. 31), indicates the ET has filled by 02 mb but its general position is the same. However the cold front remains further offshore in the analyses, which results in 850 mb winds from the southwest instead of the west.

This strong onshore flow agrees with the 5000 ft flow from the profiler, (Fig. 32), but not in the lowest 1500 ft. The lowest 1500 ft is influenced by topography in this case and not a land/sea breeze. The profiler's position in the Salinas valley is surrounded by two mountain ranges, the Sierra De Salinas to the southwest and the Gabilan range to the northeast. The average height of these ranges is approximately 2000 to 3000 feet. Below this level, the profiler is showing southeasterly flow and above this level, onshore or westerly flow. Below the 2000 to 3000 ft layer, lower surface pressure in the Monterey Bay relative to the inner Salinas valley (Fig. 33), in conjunction with the surrounding mountains, is inducing a gap flow from the southeast, which can be seen in the profiler time series.

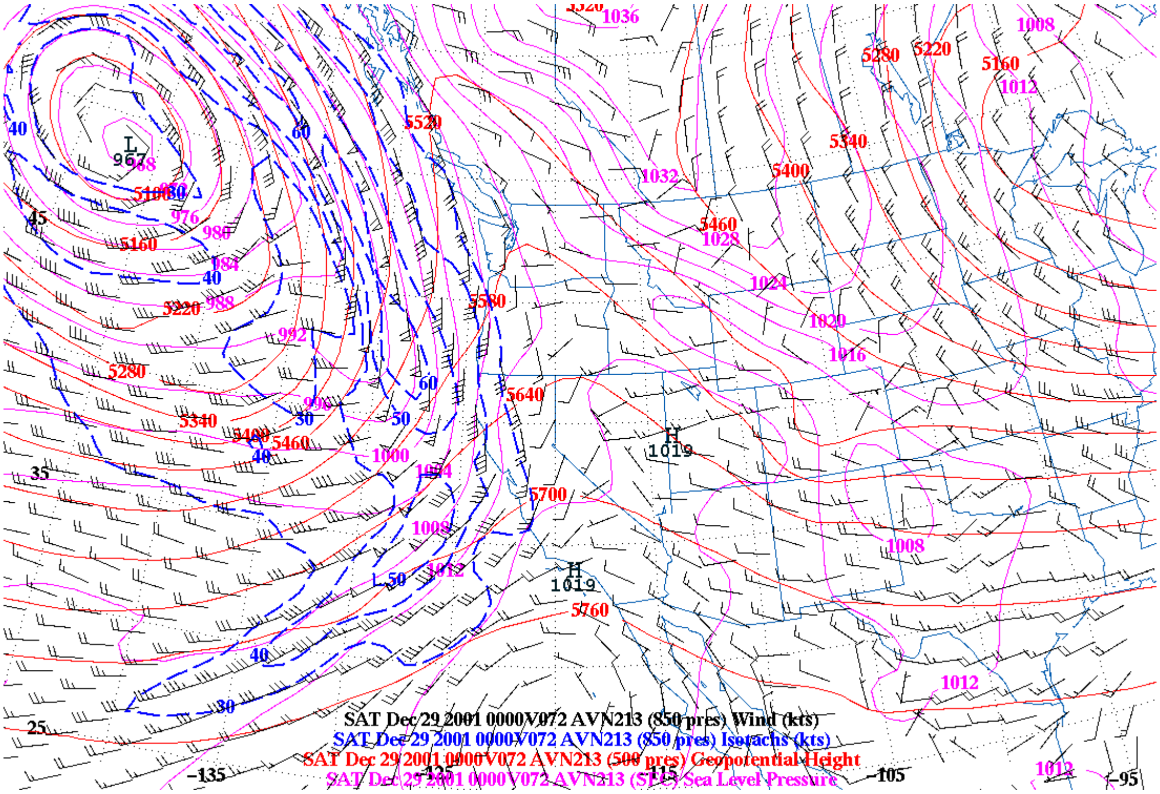

FIGURE 30. 72 hr AVN 1200 UTC onshore flow model forecast of sea level pressure (pink lines), 500 mb heights(red lines), and 850 mb winds (black barbs).

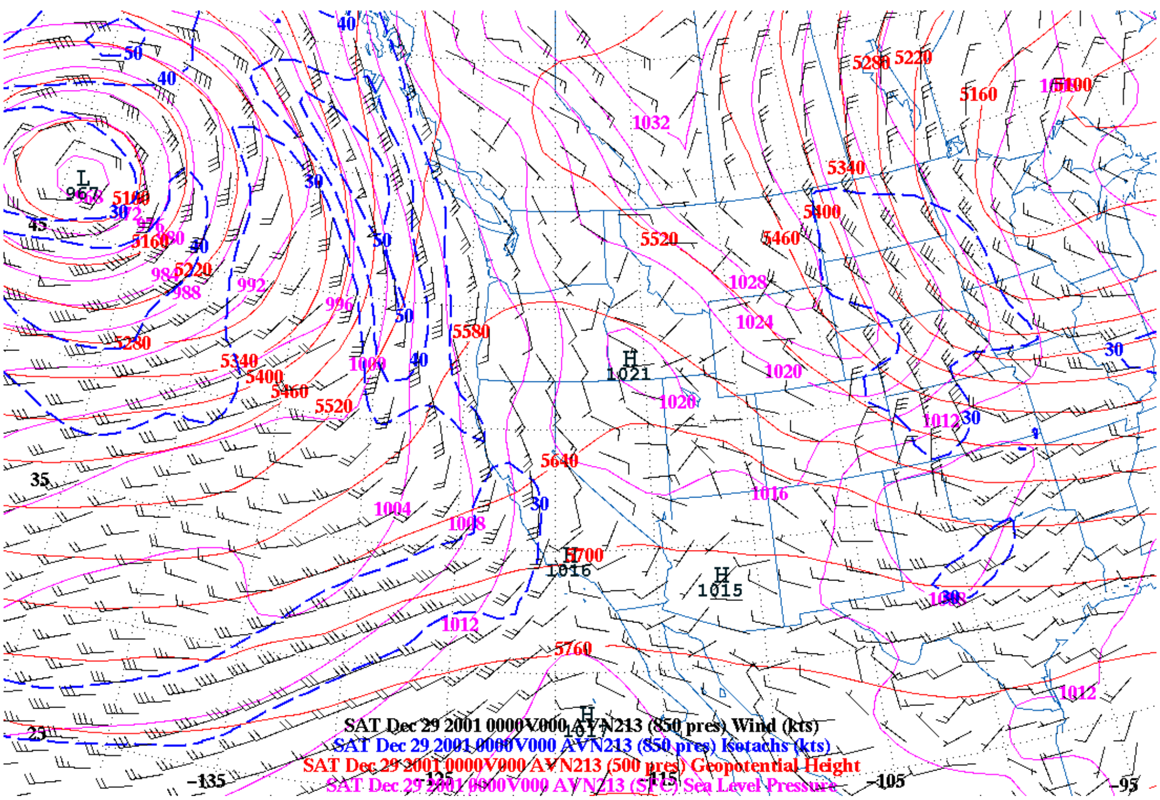

FIGURE 31. 29DEC2001 AVN 1200 UTC onshore flow analysis

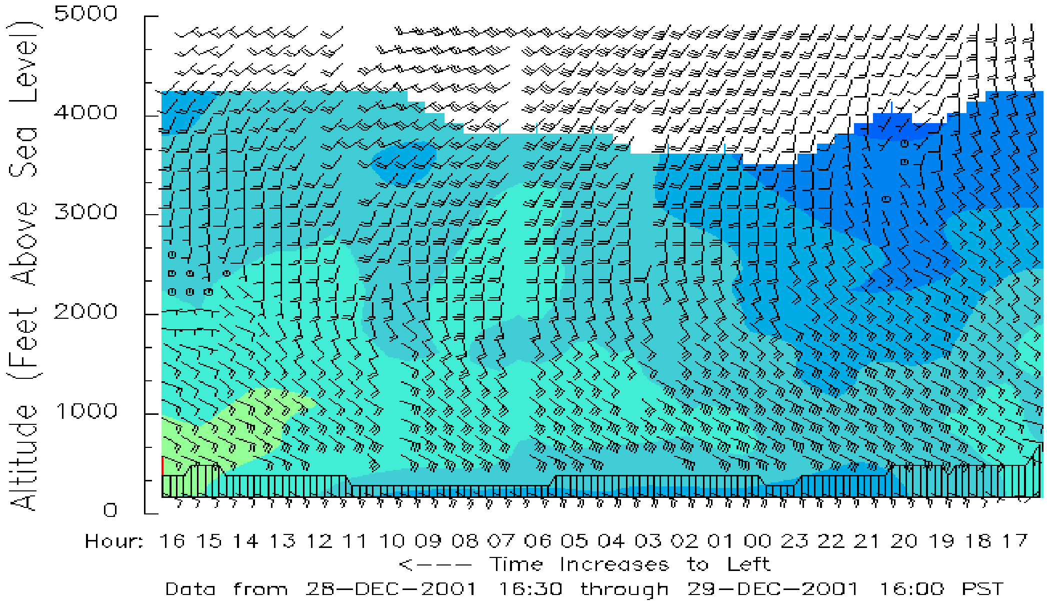

FIGURE 32. 28-29DEC2001 onshore flow profiler time and vertical section image, surface to 5000 ft winds (black barbs).

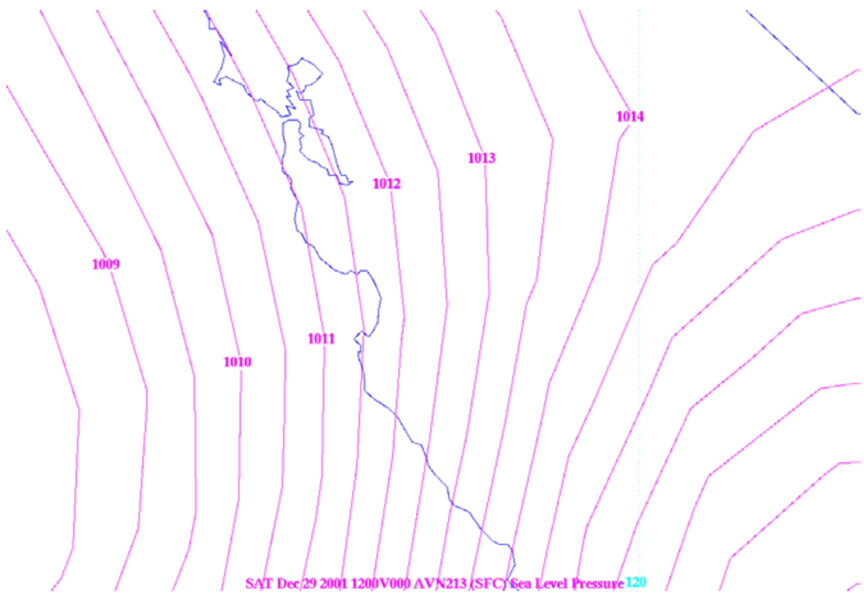

FIGURE 33. The surface pressure isobars (pink lines) over the Fort Ord area on 29 DEC 2001 analysis.

Above this layer, the onshore geostrophic westerly flow is dominant causing the wind to veer with height above the profiler. This example shows that even with strong synoptic

forcing, sometimes various mesoscale effects other than diurnal forcing can alter the flow over Fort Ord in the lower-levels. The occurrence of this type of event is much lower in frequency when compared to diurnally forced wind events.

VI. DISCUSSION AND CONCLUSIONS

The goal of this study was to improve the ability to forecast burn prescription parameters by assessing the model performance in predicting offshore flow conditions. Baseline offshore flow 24, 48, and 72 hr forecast verification percentages based on analyses of 73%, 68%, and 50%, respectively, were determined in this study. These results are not uncommon for numerical weather prediction (Nuss 2003) and indicate the methodology used in the study was consistent with other verification approaches.

A more stringent verification of these same offshore flow forecasts was done using profiler observations. This produced forecast verification percentages of 35%, 37%, and 30% at the 24, 48, and 72 hr forecast durations, respectively. The drop in verification percentage was shown to be the result of differences between synoptic scale flow and local conditions over Fort Ord. Meteorological examples were cited to illustrate synoptic and local events that result in correct and incorrect verifications. This study has dealt exclusively with forecasts of offshore and onshore flow and has not examined the forecast skill of another critical burn prescription parameter, the vertical mixing height. The ability to predict all aspects of the burn prescription simultaneously further complicates the problem but is linked meteorologically.

A. IMPACT OF INCLUSION OF VERTICAL MIXING HEIGHT

The meteorological conditions that promote the burn prescription parameters of a 1500 ft minimum mixing height,

in conjunction with offshore flow and their combined forecast verification percentages will be examined to illustrate the relationship between them. The burn prescription is aimed at large-scale meteorological conditions that produce low-level offshore flow, (Nuss 2003). These conditions are represented by high pressure over Nevada, rather strong offshore flow from the northeast at 850 mb, and upper level ridging over the west coast (Fig. 34). While these conditions are relatively well defined, they do not always produce acceptable offshore flow and a minimum mixing height of 1500 ft at the same time. This is due to two competing effects that must combine for an acceptable burn day.

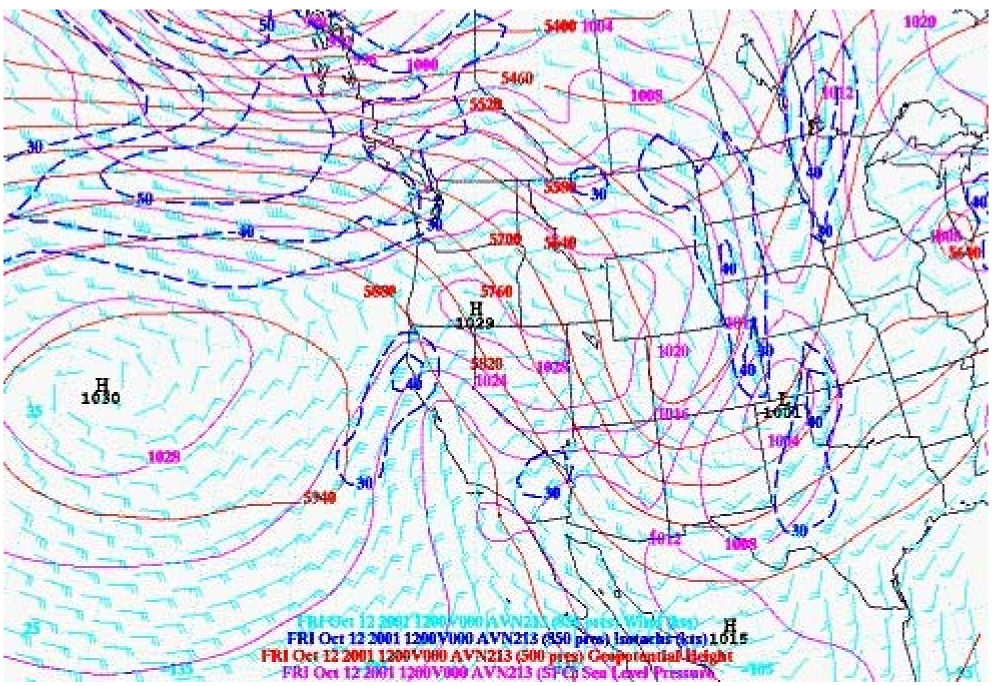

FIGURE 34. Horizontal chart of sea-level pressure (pink lines), 500 mb heights (red lines) and 850 mb winds (blue barbs) for 12 Oct. 2001. This is a sample of weather conditions for offshore flow.

The first effect is that stong offshore flow through a deep layer, from the surface up to 3000 ft or more, tends to produce very warm temperatures just above the surface, which can limit the lower mixing height well below the minimum 1500 ft level, (Nuss 2003). Figure 35 shows a profiler time series as a good example of an inadequate lower mixing height due to warmer temperatures above the surface. From 1800 on the 4th through 1600 on the 5th of October 1996, the lower mixing height remains near the surface of the NPS profiler or 51 meters ASL, which is far below the required 459 meters or 1500 foot minimum.

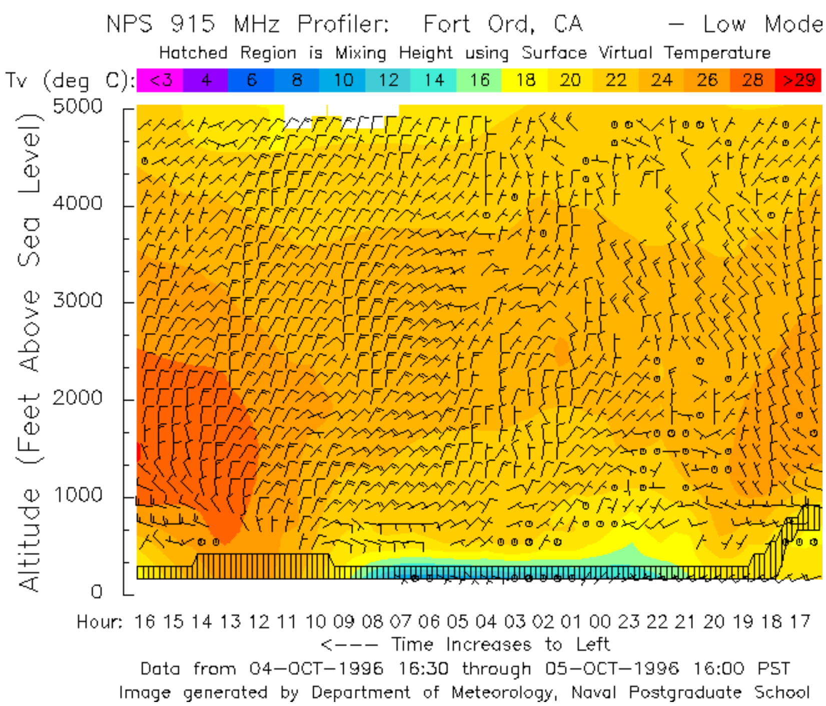

FIGURE 35. Time and vertical section of wind profiler wind, mixing height, and virtual temperature for 5 Oct 1996. The virtual temperature is color filled in 2-degree bands.

If conditions, such as cooler temperatures aloft are present vertical mixing is usually promoted, but this is not typical of offshore flows.

Conditions in which the offshore flow tends to be weaker are generally more likely to also remain cool aloft to allow favorable vertical mixing, (Nuss 2003). Figure 36 demonstrates a profiler time series where there are cooler temperatures aloft during weak offshore flow on 12 October 2001 from 1000 through 1400. For most of that time, the lower vertical mixing height is well above the minimum 1500 ft burn prescription requirement. This acceptable minimum vertical mixing height, associated with cooler temperatures aloft, is also seen during times of weak onshore flow (Fig. 37).

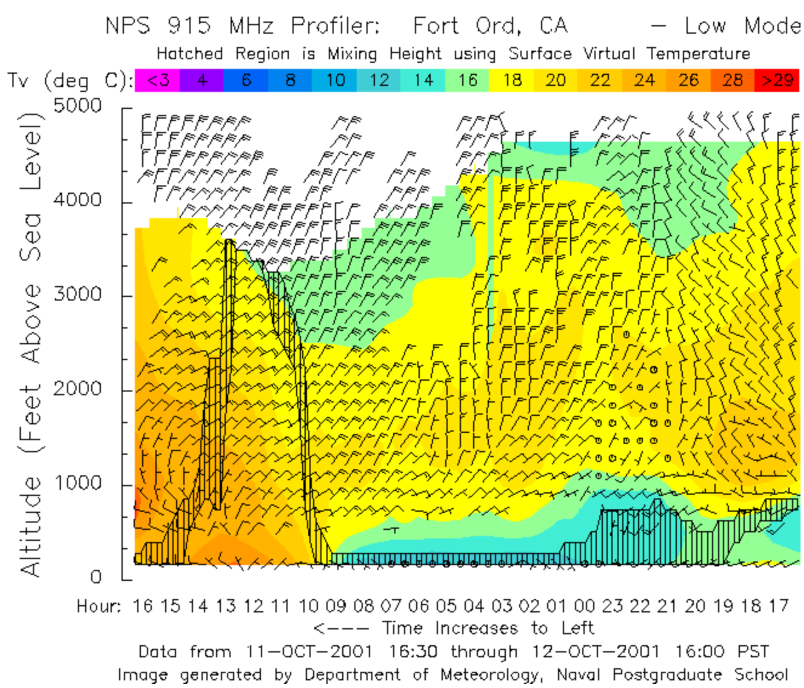

FIGURE 36. Time and vertical section of wind profiler wind, virtual temperature, and mixing height for 12 Oct. 2001. The virtual temperature is color filled in 2-degree bands.

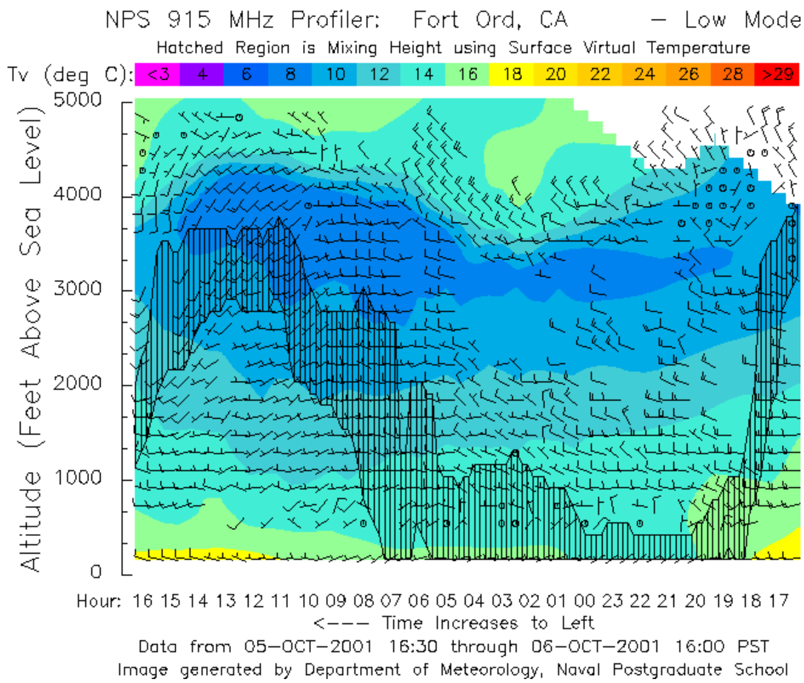

FIGURE 37. Time and vertical section of wind profiler wind, virtual temperature, and mixing height 05 Oct. 2001. The virtual temperature is color filled in 2-degree bands.

For example, during 05 October 1997 from 0900 through 1600 the lower mixing height is above the minimum 1500 ft level, during weak onshore flow or a weak seabreeze. The meteorological conditions must prevent stronger warming aloft while allowing offshore flow and warming at the surface.

During times of weak offshore and weak onshore flow conditions, there is a second effect that becomes relevant to meeting the burn prescription, the sea breeze. The sea breeze, under these weak offshore or onshore flow conditions, is typically stronger and its onset earlier in the day. A seabreeze or light onshore flow does not always create adequate vertical mixing. Cool air advected onshore by a sea breeze near the surface causes the mixing height

to drop rapidly, on the order of minutes, to unacceptable levels to conduct controlled burns (Nuss 2003).

A balance between too much warming aloft in offshore flow and surface cooling by the sea breeze must occur to result in meeting all aspects of the burn prescription. Moderate offshore flow, strongest near the surface, tends to retard sea breeze onset until 1300 to 1500 in the afternoon. This allows the minimum 1500 ft lower mixing height to be extended an additional three to four hours into the afternoon allowing more time to possibly conduct a controlled burn, (Nuss 2003). These conditions are recognizable through direct observations but have not been assessed through forecast verification. An initial estimate of forecast skill can be inferred by starting with the profiler verified offshore flow forecasts, which verified at 35%, 37%, and 30% for the 24, 48, and 72 hr durations respectively, and including the additional factor of the mixing height. In this case not only must the wind direction be correct but also the occurrence of sufficiently deep vertical mixing must occur. When only those forecasts that verified for both criteria were included, the accuracy of these forecasts dropped to around 10% regardless of forecast duration, (Nuss 2003). This indicates the difficulty in forecasting the mixing depth.

In conclusion, the ability to correctly predict favorable meteorological conditions for controlled burns is very limited. Synoptic forecast skill drops to marginal levels by 72 hrs, when predicting the basic weather pattern. Requiring verification of the forecast by the actual winds at the Fort Ord profiler and that the mixing depth verify as well results in virtually no skill at

predicting burn conditions. Consequently, approaches that minimize reliance on the forecast must be used to mitigate the costly occurrence.

B. RECOMMENDATIONS

Synoptic model forecast skill of offshore and onshore wind flow was calculated in this study, from which the simultaneous forecast skill of vertical mixing height was also inferred. These results were indicative of forecast performance, but not totally conclusive because of limitations in the approach. Some additional research opportunities that address these limitations are as follows:

1. Reduce burn contractor mobilization and notification time to as close to 24 hrs as possible. This would enable the use of a mesoscale models to be utilized. The verification percentages established in this study need to be recalculated and may improve, using higher resolution model fields.

2. Examine profiler verified 24, 48, and 72 hr forecasts of the surface to 1500 ft wind field. Instead of comparing the 850 mb or 5000 ft wind level a more direct comparison between the model and observations may improve current results. This could be done using synoptic or mesoscale models, again depending upon burn contractor constraints.

3. Calculate the forecast verification percentages for vertical mixing height, offshore flow from the surface to 1500 ft, and minimum daytime temperature. Directly compute forecast verification percentages for mixing height and compare these to inferred values. Calculating the

forecast skill of each parameter would establish the degree of difficulty each is to predict.

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